University of Alberta

Cooling Strategies to Reduce Thermal Stress in Broiler Chickens

by

Juan Carlos Segura

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Sciences

in

Bioresource and Food Engineering

Department of Agricultural, Food and Nutritional Science

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Dedicated to:

My wife **Naamah**

Her love and constant support gave me the strength to develop this thesis.

Muchas gracias mi dulcesita.

My parents and parents' in-law,

Elvia and **Rafael**

Perla and **Ehud**

And my siblings **Magaly, Edith, Rafael and Milena** and

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Abstract

High temperatures during the summer months can be stressful to the broiler chicken during the last weeks of rearing. Two trials were conducted to test the effect of high fluctuating temperatures on feed and water consumption, individual bird live weight performance, and mortality on a total of 4,800 birds. In trial one, the treatments were: control (cyclic temperatures from d29 (15 - 25 °C) to d42 (20 - 35°C)), thermal conditioning, nocturnal cooling and diurnal cooling treatments. In trial two, the thermal conditioning treatment was substituted by the commercial recommended temperature regime. Treatments were replicated beginning at d29. Feeder and water consumption were weighed electronically every 10 minutes. Overall, feed consumption, feed conversion, final bird body weight, and bird mortality did not show differences between treatments. The thermal mass (time constant) of a water container in the bird space was similar between treatments. This may explain the similar bird response between treatments.

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List of Symbols and Abbreviations

AEPEC	Alberta Egg Producers Environmental Chambers
BEI	break even income
BW	body weight (g or kg)
CV	coefficient of variation
d	day
FCR	feed conversion ratio
g	gram
HSI	heat stress index (°C*bird age)
kcal	kilocalorie
L	litre
lx	lux
m	meter
ME	metabolizable energy
mL	milliliter
R^2	correlation coefficient
RH	relative humidity (%)
s	second
SDS	sudden death syndrome
SEM	standard error of the mean
Std Dev	standard deviation
T	temperature (°C)
t	time (h or min)
τ	time constant
wk	week

1. Introduction

High temperatures during the summer months are a major concern among broiler producers in the Prairie Provinces. The hot days in addition to high stocking densities can create a poor environment for the broiler chickens, especially during the last week of rearing. This increases the risk of significant economic losses to the producers. There has been considerable research into investigating the effect of environmental temperatures on broiler performance, body temperature, and water consumption. Many of these studies applied heat stress treatments with high constant ambient temperature, or minimum temperature variations. Much of the research conducted also assumed that the poultry barns have proper ventilation controls that deviate little from the desired temperatures. However, the environmental conditions can be very unpredictable (non-typical) under commercial-scale operations during warm weather conditions. At times, poultry producers are unable to have well-controlled environments in their barns during hot weather conditions. Sudden temperature peaks, such as those occurring during the summer time, can exceed the cooling capacity of a barn thus affecting the bird performance, or in the worst scenario, leading to high bird mortality. It was for these reasons that the research undertaken for this project included a wide range of temperatures from 15 °C at night to 35°C during the day, thus simulating the warm weather conditions within many poultry barns.

This study also looked at how birds may perceive the temperature fluctuations around them. The microclimate or air temperature at the bird level was measured with a thermistor located inside a black bottle filled with water. The purpose of this measurement was to find a sensor that can help describe how the bird perceives the high surrounding temperature fluctuations. This may explain the stress to the broilers

and will prove invaluable in understanding the broilers heat stress and, thus, strategies to control temperatures in the barns.

1.1. Literature Review

Little information was found concerning poultry mortality related to high temperature fluctuations in commercial farms. Hyink (2001) indicated that producers have high losses during summer time due to high temperatures, especially during the last stage of the birds' growth. In Georgia, poultry producers lost over one million chickens and turkeys in one month because of high temperatures (Brown, 1986). In the Provinces of Alberta, Ontario and Quebec more than six hundred thousand chickens died in June of 2002 due to the high temperatures (Gerein, 2002). Given the magnitude of this problem, it is interesting to note that there are no statistics available on bird mortality due to heat stress and the economical impact on the Canadian poultry industry. The issue of poultry mortality due to high temperatures is an important concern that needs to be investigated from the barn temperature control point of view.

1.1.1. Broiler Physiological Responses to High Temperatures

Curtis (1981) concluded that the effects of warm or hot environments on animals are greater than those of cold or cool ones. This suggests that animals can thermo-regulate more effectively in cold environments than in hot ones. Animals cannot survive for long periods at environmental temperatures 5 °C or higher than normal body temperature, but they can survive at temperatures 20 °C or more below normal body temperature.

It is important to stress that birds have no sweat glands so their body temperature is regulated by evaporative cooling from the respiratory tract (latent heat loss) and by heat loss from their bodies (sensible heat loss). These two mechanisms

are under behavioral control: panting increases evaporative cooling and wing raising exposes the poorly feathered sides of the body and under-wing area (Appleby et al, 1992). When a bird or a mammal has difficulty dissipating heat it will lower its metabolic heat production and maintain homeothermy by reducing its feed intake which results in slower growth.

If bird performance is considered in basic terms, performance is the conversion of feed into meat or eggs and in this document the term feed conversion ratio (FCR) will be used to define the efficiency of the performance. For example, in a broiler flock with an FCR of 1.70, 1.70 kg of feed is used to produce every 1.00 kg of live weight. May *et al.* (2000) confirmed that performance is reduced because energy is expended for panting, and growth is slowed due to the lower feed consumption. Furthermore, due to improvements in bird genetics, type of feed, and better management procedures birds now develop faster than in previous years and thus go to market earlier. However, this increased development time also causes birds to produce more heat per day.

Birds in densely stocked barns have more difficulty dissipating heat from their bodies because the air between the birds can be more stagnant due to less air movement. This can occur even though the airspace above the birds appears to have good air quality and at be an acceptable temperature. The data on bird heat production are highly variable because of factors involved such as: bird genetics, caloric value of the feed, ambient temperature, and relative humidity. Feddes *et al.* (1984) estimated a 17 W total heat output of a broiler which was calculated by measuring the energy intake of the bird, efficiency of feed utilization and the metabolizable energy in the feed.

Core body temperature in poultry has been used as an indicator of the degree of heat stress in chickens (Smith and Oliver, 1971). Leeson (1986) mentioned that the term 'heat stress' is frequently used to define the birds' response to mainly warmer environments where some different or abnormal physiological response, such as

panting, is observed. Cooper and Washburn (1998) found that broilers exposed to a hot environment (21 and 32 °C) had performance that negatively correlated with body temperature after one week of heat exposure.

May and Lott (2000a) reported that the effect on broilers due to lower temperatures during 1-7d period affected mortality but did not affect weight gain or feed conversion during the 21d project. Several other studies have also looked at live performance of broilers at high environmental temperatures. Lott (1991) found that water consumption is a main component of acclimation of broilers to hot temperatures. Water must be available to meet this peak demand. Donkoh (1989) found that water consumption increased with rising ambient temperatures from 20 to 35 °C but growth rate, feed intake, and feed conversion of the broiler decreased when compared with the lower temperature.

Arjona *et al.* (1988) reported that conditioning broilers to high ambient temperatures at 5d of age increased survival when they were exposed to high ambient temperatures later in life. Yahav and Hurwitz (1996) and Yalcin *et al.*, (2001) also used a similar technique of thermal conditioning at day 5, or days 5 and 7. They concluded that thermal conditioning at a young age may take advantage of the immature mechanism that regulates body temperature of young birds (Yahav and Hurwitz, 1996). Their results suggest that chicks exposed to 36 ± 1°C and 70 to 80% relative humidity (RH) for 24 h during day 5 had a lower body temperature and mortality when they were exposed to temperatures of 35±1°C and 20 to 30% RH at 42d of age.

1.1.2. Thermo-neutral zone

To optimize feed utilization and body weight gains of broiler chickens, environmental temperature should be near 21 °C (Deaton *et al.*, 1978). There is a narrow range of environmental temperature in which poultry utilize minimal energy to

maintain body temperature. This range is known as the zone of thermal neutrality, thermal-comfort or thermo-neutral zone (Yousef, 1985). A variety of temperature ranges can be found in literature as the thermo-neutral zone. However, each given range has to be associated with different factors that could influence the ability of poultry to cope with high environmental temperatures. These include relative humidity, diet, genetics, ventilation rates, age, adaptation, weight, and diurnal temperature variations. Van Kampen *et al.* (1979) specified a thermo-neutral zone for White Rock males between 32.2 and 37.7 °C during the day and lower temperatures during the night ranging from 27.5 to 37.7 °C. Deaton *et al.* (1981) found that laying hens exposed to a 24h linear temperature cycle ranging from 26.7 to 35°C (8.3°C cycle) had a significantly poorer egg shell breaking strength, a thinner egg shell, and a significantly greater body-weight change than hens exposed to temperatures cycles of 21.1 to 35 °C (13.9 °C cycle) and 15.6 to 35°C (19.4°C cycle).

Since the water content in a broiler's body is up to 70% of its weight, birds need to have a constant supply of water to keep this percent at normal levels and also to maintain a constant deep-body temperature, especially during hot weather. The amount of water necessary to remove the heat from the broiler's body increases rapidly as the barn (house) temperature rises above the zone of thermal comfort of 18.3 to 21.1 °C while ambient temperatures below 18.3 °C have minor effects on water consumption (North and Bell, 1990).

1.1.3. Factors that Can Influence Birds in Adapting to High Temperatures

Due to the fact that the source of heat, aerial contaminants and pathogens are at the birds' level; the strategy to maintain good air quality in the vicinity of the birds is to encourage a high rate of air exchange between the birds' space and the airspace above.

In many countries extensive research programs focus on the question of how birds can acclimatize to hot environmental conditions.

Also, extensive research is being carried out on temperature fluctuations associated with poultry barn characteristics. McGovern (1997) evaluated the effects of diurnal temperature fluctuations and removal of respirable dust, by application of canola oil to straw litter, on growth, carcass traits, and the degree of ascites. The temperature treatment consisted of a fluctuation of 3 °C in temperature above the required temperature during the day (6 to 18 h) and 3 °C below the required temperature at night (18 to 6 h) for a 6 °C cyclic change in daily temperature. The final BW of the broilers were significantly different ($P<0.05$), and the interaction between oiled-litter treatments and temperature fluctuation had lower weight gain compared with the interaction between no-oiled litter and temperature fluctuation treatments. The *minor* and *major Pectoralis* muscles weights were significantly heavier ($P=0.021$ and $P=0.048$ respectively) in the temperature fluctuation treatment than in the control temperature treatment. Temperature fluctuations resulted in a 1.4% increase in the incidence of mortality. Temperature fluctuations negatively impacted broiler growth due to heat loss when litter oiling was excessive.

May *et al.*, (1997) investigated water consumption of broilers at high cyclic temperatures between 24 to 35 °C (11°C cycle). The authors noted similar water usage with a bell-type drinker and nipple drinkers during the lower temperatures but reduced water usage for the nipple system during the high temperature part of the cycle. Lott *et al.* (2001) compared the effects of an open-type drinker and differing nipple heights on production parameters of broilers at 25 or 30 °C. May *et al.*, (2000a) conducted a project to determine the effect of two ranges of air velocity (AV) (<15 and 120 m/min) on feed and water consumption at a constant temperature of 27 °C and a daily cyclic temperature of 22 – 32 - 22 °C (10 °C cycle). The study demonstrated that broilers

exposed to the high AV consumed less water and more feed and that for both velocities the feed and water consumption decreased during the peak of the daily cyclic temperature.

Yahav *et al.*, (2001) tested the effect of air velocity on weight gain, feed intake and feed efficiency in male broiler chickens exposed to a constant 35 ºC, 60% RH, and continuous illumination from 4 through 7 wk of age. They concluded that AV had a significant effect on broiler performance with the optimal AV being 1.5 to 2.0 m/s. These projects are a few examples that reflect how a combination of different environmental factors, besides temperature, such as RH, photoperiod, and air velocity, can affect the normal development of the broilers.

1.1.4. Effect of Environmental Temperatures on Other Species

In other species, it has also been noted that the environmental temperatures have an influence on the physiological response of the animals. Both in dairy cattle (Scott *et al.*, 1983) and feeder pigs (Whittington, 1999), cooling the animal airspace during the night hours, when rectal temperatures are the highest, has been effective in increasing feed intake. Convective heat transfer cools the animals, and the cooler temperatures stimulate their appetite (Brumm and Peo, 1994). By decreasing the diurnal temperature range, animals can dissipate excess body heat accumulated during the day more effectively and therefore, do not need to reduce their feed intake. Nienaber *et al.* (1996), and Feddes and DeShazer (1988) noted that feeding patterns change for pigs exposed to hot environments. Pigs consumed more meals but with less duration. This can have implications for broilers in terms of feeder space. There may be more synchronous feeding at high temperatures thus taxing the feeder space.

1.2. Research Objectives

The goal of this thesis is to investigate the effect of high environmental temperature fluctuations on feed and water consumption, live weight performance and bird mortality.

To achieve this goal, two trials were conducted to test the following hypotheses. The testing of these three hypotheses is the primary objective of this thesis.

1) That diurnal fluctuating temperatures help the birds to acclimatize to high summer temperatures thus reducing mortality during the last two weeks of rearing and maintaining a satisfactory bird live weight performance.

2) That lowered nocturnal temperatures (to 15 °C) can increase or maintain a satisfactory bird live weight performance and help it to cope with high mid-day temperature at the end of the rearing cycle thus reducing the mortality rate.

3) That thermal conditioning at the age of 5d increases bird live-weight performance and helps it to cope with high midday temperature peaks during the last two weeks of rearing thus reducing the mortality rate.

The secondary objective is to determine if:

4) The temperature of a water container at the bird level describes the bird's response to warm temperatures.

5) The calculated heat stress index is related to bird performance

2. Materials and Methods

The Faculty Animal Policy and Welfare Committee of the Faculty of Agriculture, Forestry and Home Economics of the University of Alberta approved the experimental protocols.

2.1. Birds

In both trials, 306 male Hubbard x Hubbard broiler chicks were placed in each of the eight AEPEC chambers after being counted and weighed in groups. All the chicks were from the same parent flock.

2.2. Alberta Egg Producers Environmental Chambers (AEPEC)

The 'Alberta Egg Producers Environmental Chambers' (AEPEC) are designed with the latest control technology for poultry environmental research. Scientists and students can simulate a variety of conditions related to poultry housing (floor or cage reared birds) while measuring the response of the birds in an accurate and convenient manner.

The dimension of each AEPEC chamber is 4.45 m (l) by 3.85 m (w) by 3 m (h) giving an area of 17.13 m^2, which equals to 18 birds/m^2 or 0.05 m^2/bird. The non-utilizable space, the area occupied by the four hanging tube feeders of 0.4 m in diameter, was assumed to be 0.5 m^2.

An IBM compatible personal computer (PC) installed in the instrument room (Figure 2.1) was used to operate the virtual instrument program written in LabView Version 5.1.1 (LabView, National Instruments Inc. Austin, TX). The computer with the virtual instrument program allows the researcher to monitor and control the chambers' environments.

The AEPEC chambers were selected at random for each treatment to minimize statistical variance; although all chambers are assumed to be the same except for the location of the air inlet and exhaust opening. It was assumed that the ventilation locations would not significantly change the environmental conditions.

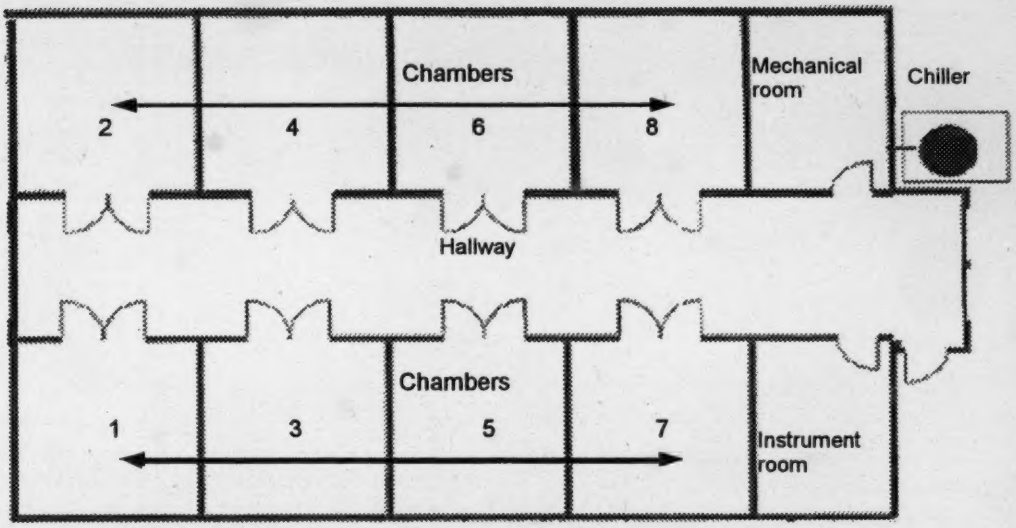

Figure 2.1. Top view of AEPEC chambers distribution, the mechanical room and the instrument room.

2.2.1. Water Consumption Measurements

In each chamber, a PVC nipple drinker system was set up along three of the chamber walls with a total of 34 nipples (9 birds / nipple) and 0.25 m distance between nipples (Figure 2.2). The nipple drinker water line was directly connected via a pressure regulator (VR-202, Val Products Inc. Lancaster, A.) to a 20-L water container. The container was set on top of a digital scale with a PC interface, which was connected to a data acquisition and a graphic control computer program (LabView, National Instruments Inc. Austin, TX). The computer program was designed to begin filling the water container when the weight of the container was 7 kg (7 L) and to stop filling at 14.1 kg (14.1 L).

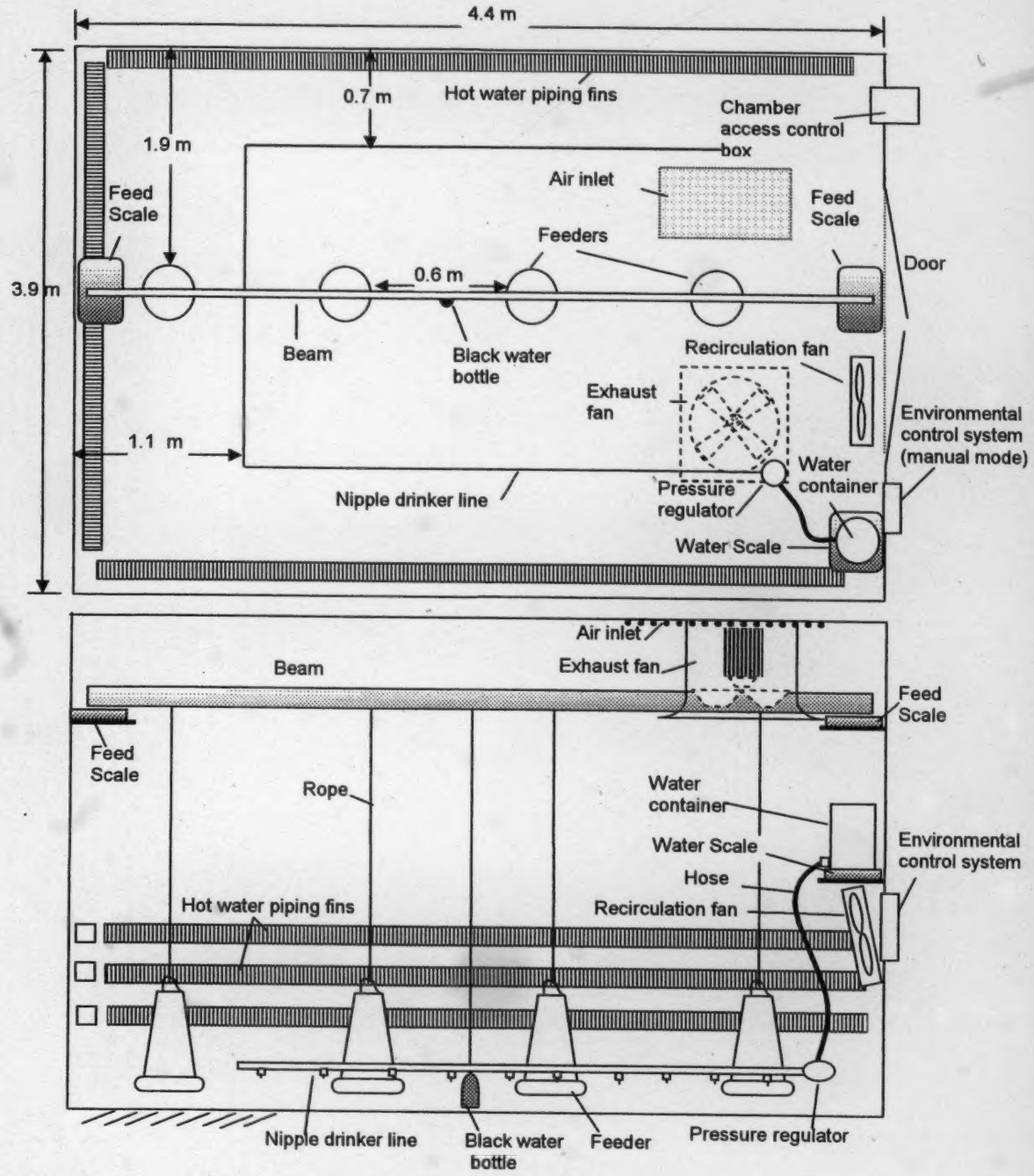

Figure 2.2. Individual chamber layout, top and lateral view.

2.2.2. Feed Consumption Measurements

In both trials, all the birds were fed a standard starter diet (3,000 kcal ME/kg of diet, 21.3 % crude protein) from 1-3 weeks of age and from 4-6 weeks of age the broilers were feed a standard grower diet (3,000 kcal ME/kg; 18.8 % crude protein). In all treatments, feed and water were supplied *ad libitum*.

Four pan feeders with a holding capacity of 22.6 kg each were located in the middle of each chamber (Figure 2.2). The feeders were hung from a beam by a rope. The beam was supported at the ends by two scales similar to the scale used for the water system. The weights of the feeders were monitored every 10 minutes. The difference between 10 min. readings represented the feed consumption for that period of time.

The digital scales were (Model 4010CN, Pelouze, Signature Brands Inc., Bridgeview, IL) used for feed and water measurements with a manufacturers rated capacity of 65 kg and a resolution of 0.1 kg. The signal from a malfunction was recorded as 99.9. Malfunctions include electronic noise and scales auto shut-off not being disabled These values were modified by linear interpolations, between the last good reading before the 99.9 error message and the first good reading after the 99.9 error message appeared. Linear interpolation was also used for those erroneous values that occurred when feeders were filled or when researchers moved the feeders or drinking lines. Water scales were disturbed less often due to no contact with the birds or other physical apparitions.

2.2.3. Ventilation

Ventilation was provided by one 558 mm exhaust fan (Fancom, Panningen, Holland) per chamber. The air was brought into the chamber through inlets as a result of negative pressure created by the exhaust fan (Figure 2.2 and 2.3). The computer

program controlled the ventilation rate depending on the desired temperature in each chamber. A ventilation rate was applied on a scale of zero to 100 %. In order to determine values for the airflow per chamber, measurements of one exhaust fan were followed, as per standards for laboratory methods of testing fans for rating ASHRAE standard 51-71 (1975).

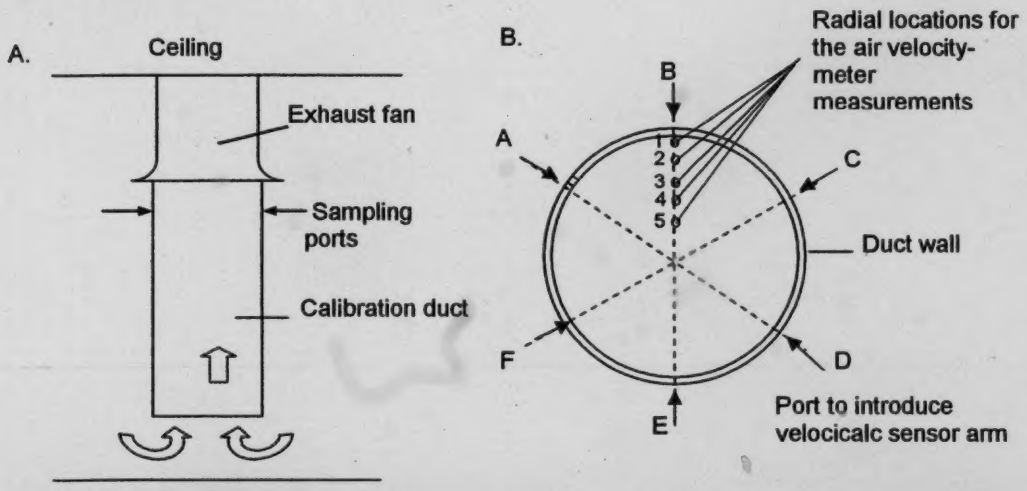

Figure 2.3. Fan calibration scheme: A) Lateral view of fan and duct. B) Traverse duct section showing the readings ports A, B, C, D, E, and F with the five different measurement locations in each port.

A duct 1.8 m long and 0.56 m diameter was used for the calibration. Six openings or sampling ports (A, B, C, D, E and F in Figure 2.3) were located in one of the ends of the duct in order to measure the air speed with a VelociCalc Portable Air Velocity Meter, (TSI, St. Paul, MN). Air velocity was measured at five different radial depths per opening in accordance with the ASHRAE standards (1975). Each depth represented 5 equal concentric areas of the test duct. It should be noted that the duct length of ten times the duct diameter (10x0.56 m) recommended by the standards was not followed because the chamber was 3 m high, making it impossible to set a calibration duct of 5.6 m inside the chamber.

A minimum ventilation set point of 15 % (0.19 m ^{3}/s) was applied during all treatments to ensure a constant minimum ventilation rate. Each chamber had one overhead re-circulation fan that was assumed to provide adequate air circulation at the bird level (floor level) (Figure 2.2).

Table 2.1. Air flow calibration values for the AEPEC exhaust fans and ventilation rates in L/s per bird.

Fan Speed (%)	Flow (m^3/s)	L/s per bird*
10	0.07	0.25
20	0.32	1.08
30	0.60	1.99
50	1.18	3.94
70	1.89	6.31
100	2.44	8.12

*Assuming 300 birds/chamber

Chamber ventilation rate calculations and curves are summarized in Appendix C. Based on the ventilation values in Table 2.1 a fan ventilation equation, 2.1, was found using a polynomial regression.

$$y = -3E\text{-}06x^3 + 0.0005x^2 + 0.0085x - 0.0439 \quad (2.1)$$

$R^2 = 0.99$

Where y is ventilation rate in m^3/sec, and x represents the fan speed in percent.

2.2.4. Lighting

The type of light used was incandescent. From 1-3 wks of the birds' age the intensity of the light was set at 20 lx. The light intensity was measured with a Foot Candle / Lux meter (Model 407026, Extech Instruments, Tampa, FL). After three weeks the birds were observed to be too active and as a result, at day 20, the light intensity was reduced to 14 lx in all the chambers. It is important to mention that at the early stages (day 1) the chicks had to learn how to find and use the nipple drinkers and they did it well with high light intensity because it allowed them to more easily locate the

yellow nipples with the attached droplets of water. Birds were provided continuous lighting throughout the 42 days of each trial.

2.2.5. Heating and Cooling System

The chambers' set point temperatures were maintained by a finned-pipe, radiant, hot water heating system (FIgure 2.2 and Figure 2.4) and by controlling the ventilation rates (the rotational speed of the exhaust fan) with the control program. Hot water was supplied to each chamber by means of an insulated pipe header located in the hallway. The header pipe was connected to a shared loop of finned pipe in each chamber. Two boilers located in the mechanical room heated up the water (Figure 2.4).

Similar to the heating system set-up, there was also an insulated cold water header pipe located in the hallway. It used the common chamber loop piping to supply the cold water provided by a chiller (Figure 2.1). However, the cooling system was not used during the project because the external temperature, due to cold weather (winter time), was low enough to maintain the minimum required temperatures.

For more technical information about the AEPEC please refer to the AEPEC User's Manual (Segura *et al.*, 2002).

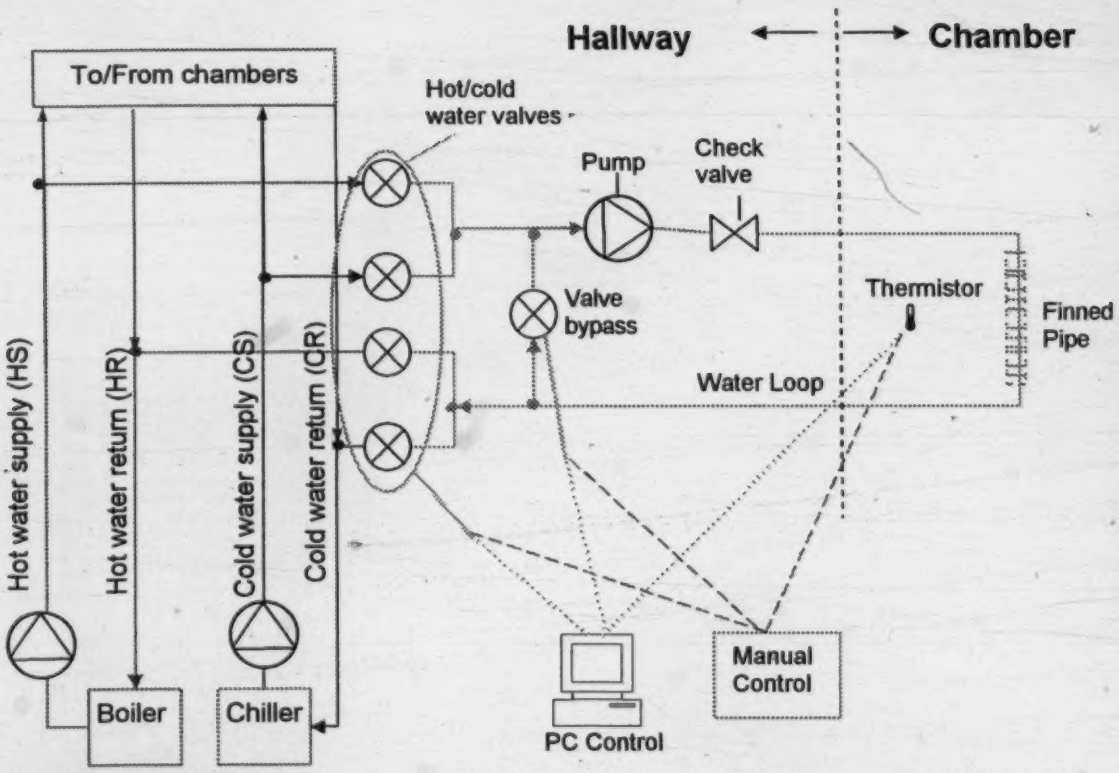

Figure 2.4. Schematic of cold and hot water circulation through AEPEC's chambers piping.

2.3. Experimental Methods (Treatments)

The following five temperature treatments were applied in this research project: control, diurnal cooling, nocturnal cooling, thermal conditioning and commercial temperature treatments. Except for the thermal conditioning treatment at 5d, the temperature for all treatments during the pre-experimental period, 1 to 28 d of age, followed the same temperature curve that is used in commercial practice as show in Figure 2.9. The curve started from 35°C at 00:00 h (midnight) and dropped to 25.4 °C by 28d.

The following sections describe the five temperature treatments that were applied.

2.3.1. Control Treatment

The temperature patterns that were used during the control treatment were repeated diurnal extremes of typical temperature fluctuations that occur during the summer months in the Province of Alberta.

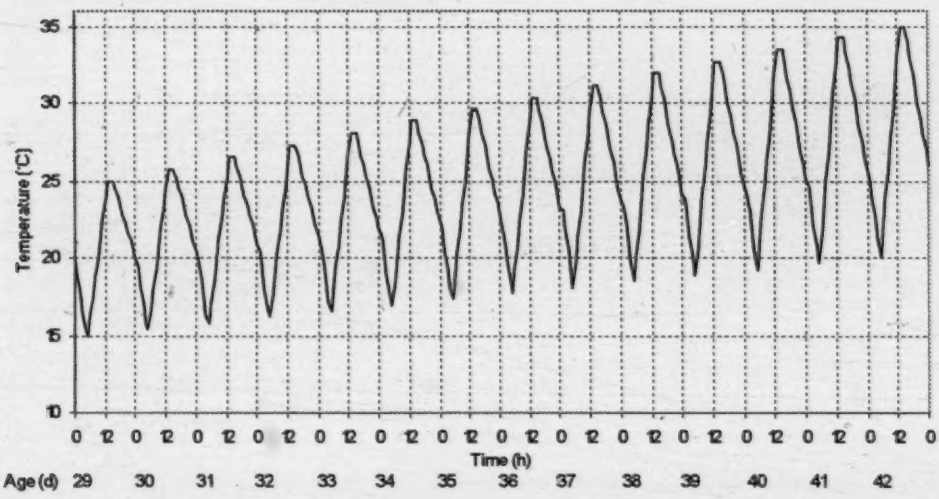

Figure 2.5. Target temperatures applied in control treatment from 29 to 42 d of age.

The control treatment consisted of a cyclic temperature curve that started at 20°C at midnight at day 29 and dropped to 15°C at 05:00 h after which the temperature rose linearly to 25°C at 13:00 h. The temperature was constant for two hours and then dropped again linearly to 15.4°C at 05:00 h. Temperature was progressively increased daily by approximately 0.8°C (0.4°C at 05:00 h and 0.4°C at 13:00 h, providing a cumulative, average, increase on temperature of 0.8°C a day) until the final temperature points on d 42 were 25°C at 00:00 h (0.4°C x 13 days), 20°C at 05:00 h and 35°C at 13:00 h (0.8°C x 13 days) (Figure 2.5).

2.3.2. Diurnal Cooling Treatment

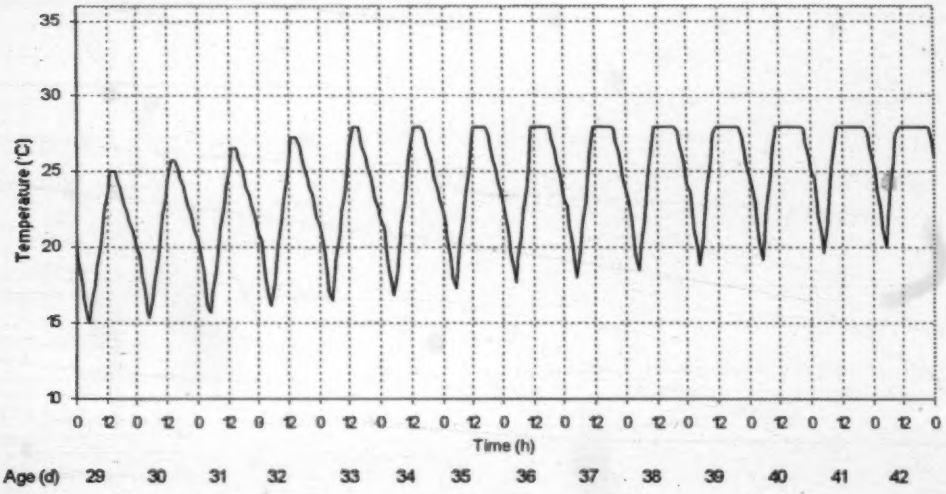

Figure 2.6. Target temperatures applied in diurnal cooling treatment from 29 to 42 d of age.

Diurnal (during the day) cooling treatment followed the same temperatures as the control treatment except that the maximum temperature allowed at midday was 28°C (Figure 2.6). Like the control treatment, at 05:00h the temperature increased by 0.4°C each day. This treatment was selected to simulate water misting (evaporative cooling) that producers apply during the summer in addition to the ventilation to cool down the birds.

2.3.3. Nocturnal Cooling Treatment

In the nocturnal (during the night) cooling treatment the temperature was lowered and maintained at 15°C, from 23:00 h to 03:00 h, thus taking advantage of the cooler air outside temperature during the night, after which the temperatures were the same as the control (Figure 2.7).

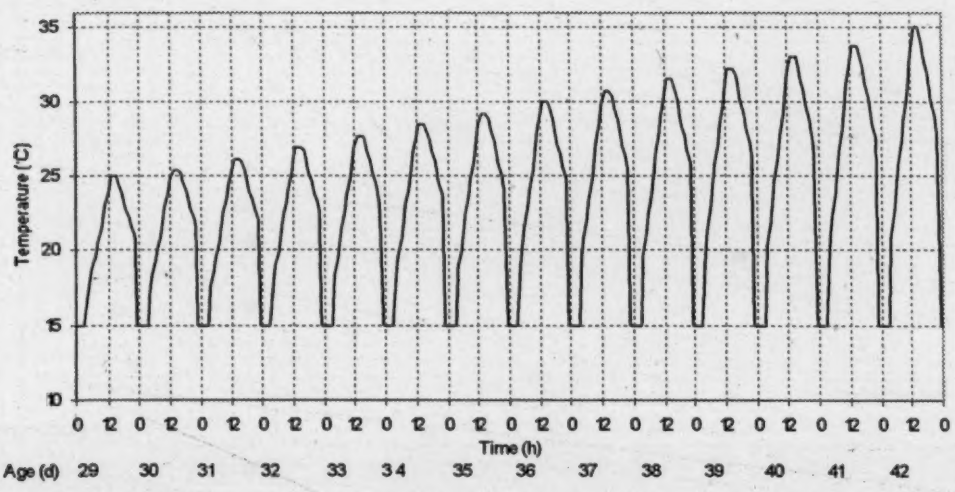

Figure 2.7. Target temperatures applied in nocturnal cooling treatment from 29 to 42 d of age.

2.3.4. Thermal Conditioning Treatment

During the thermal conditioning treatment the temperature on d 5 was increased to 40°C with 15% relative humidity (RH) for 24 h (Figure 2.8). The temperature used by Yahav *et al.* (1996) was 36°C but due to the differences in RH it was necessary to apply a 'temperature-humidity index' in order to simulate the same environmental conditions (Curtis, 1981). After 29 d of bird age the temperature fluctuations were the same as in the control treatment.

This treatment was only carried out in the first trial and was substituted during the second trial by the commercial temperature treatment. It was replaced because there was lack of statistical differences between the thermal conditioning treatment and the control treatment. Consequently, this treatment was replaced by temperatures recommended in commercial practices. A comparison of a heat stress and the commercial temperature treatment would be useful to the chicken industry.

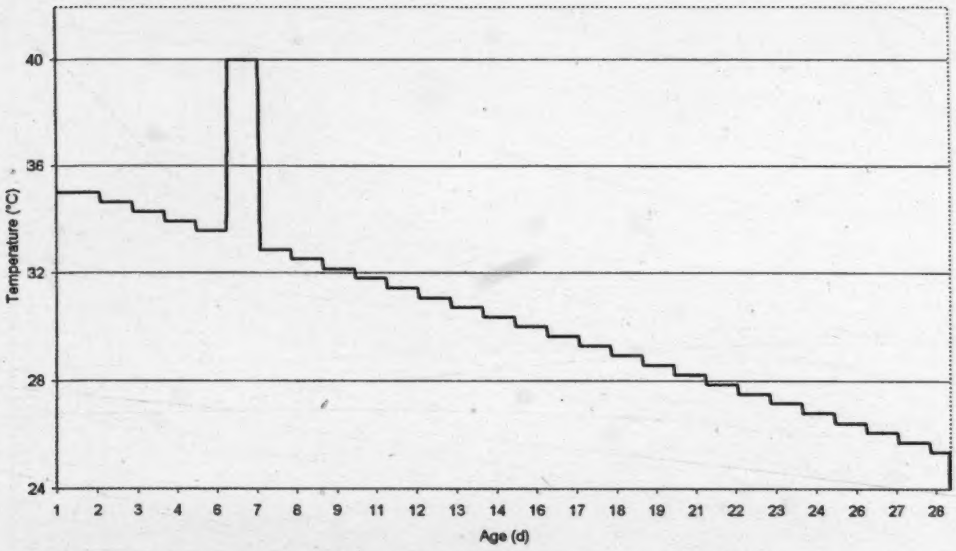

Figure 2.8. Target temperatures applied in thermal conditioning treatment.

2.3.5. Commercial Temperature Treatment

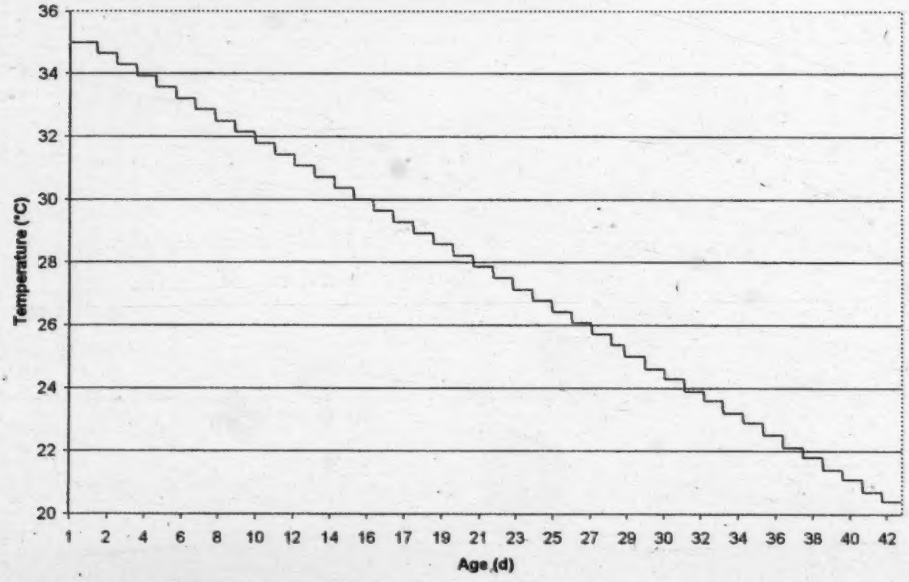

Figure 2.9. Target temperatures applied in the commercial temperature treatment from 29 to 42 d of age during trial 2.

Treatment five was applied during the second trial based on the temperatures recommended for the poultry industry that can be found in the broiler management

guides, like Arbor Acres (2000) and Agriculture Canada (1991). The initial recommended temperature (day 1) is 35°C and decreases approximately 0.4° C daily until 20°C at d42 (Figure 2.9). Figure 2.10 shows a summary of the temperature treatments from d1 to d42.

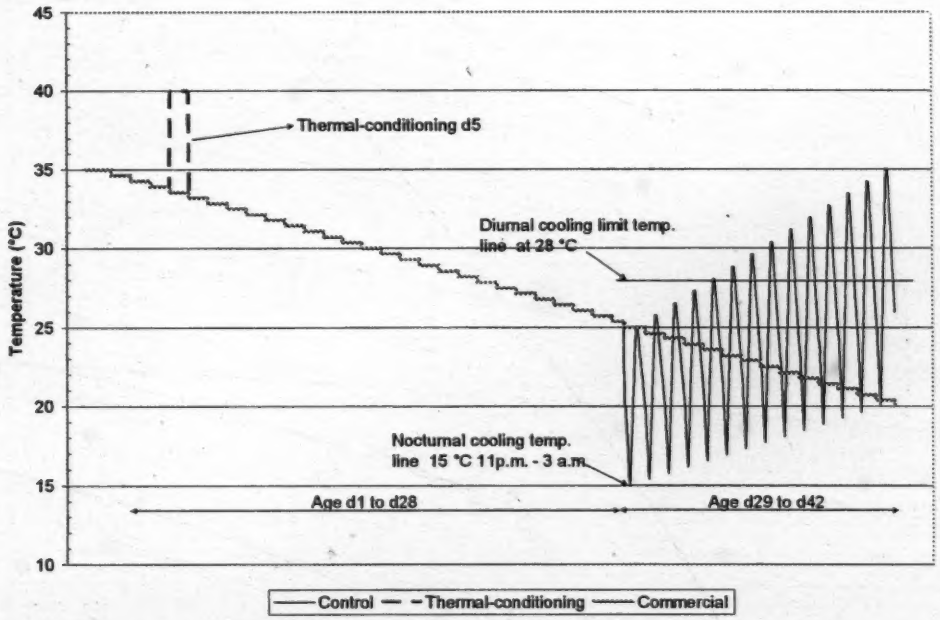

Figure 2.10. Summary of the target temperature curves for all the treatments.

2.4. Bird Body Weight (BW)

Bird body weight gain was determined at days 7, 14, 21, 29 and 36 with a group of 30 birds selected at random per chamber. Another 20 birds per chamber were weighed as part of the CHICKCOP (1997) broiler model calibration. The 20 birds were selected at random on day zero and marked (labeled) on the neck. The 20 labeled birds per chamber were weighed twice a week in order to find a growth curve under the different temperature conditions.

Mortality and culled birds were weighed, tagged and recorded daily to estimate the amount of feed consumed by the dead birds and to determine the weekly BW gain.

Also, a veterinarian performed postmortem analysis on all mortalities to evaluated the relationship between diseases and the different heat stress treatments.

2.5. Economic Analysis

An economic analysis for Alberta's poultry industry was performed using the performance data from the various temperature treatments. This analysis was used as a reference to relate the statistical analysis with daily production decisions faced by the producers. The economic parameters that were evaluated were the margin over feed and chick costs, and the total cost of production (break even income). Zuidhof (2002) provided the economic values (feed value, quota value, chick price and estimated income) that were used to run the Chickcop (1997) poultry software. The body weights (BW), feed consumption, feed conversion rate (FCR), mortality, and condemnation data specific to each chamber (pen) were used. A 50,000 quota-unit farm was simulated at 100% quota utilization on an 8 week cycle. Feed intakes values were set in kg per chamber of starter ration at $284/t; and kg of grower ration per chamber at $256/t. A chick price of $0.53/chick and an income of $1.145 / live kg were used. No financing or depreciation costs were included in the analysis in order to stress the results in feed and chick costs that are highest expenses for producers. Moreover, financing and depreciation costs are variable costs that vary among producers and are thus too specific to be analyzed in this study. The results for each chamber (pen), extrapolated to simulate a commercial flock, were statistically evaluated to determine whether there were any significant economic differences between treatments.

2.6. Statistical Methods

To facilitate the statistical analysis, the five treatments from the two trials were grouped in three different statistical models namely: Model A, Model B and Model C.

- **Model A:** Control, diurnal cooling and nocturnal cooling treatment results were compared from trials 1 and 2. Each trial was taken as a block.
- **Model B:** The four treatments in trial 1 included control, diurnal cooling, nocturnal cooling and the thermal conditioning treatment.
- **Model C:** The four treatments in trial 2 were: control, diurnal cooling, nocturnal cooling and the commercial temperature treatment.

All treatment effects and interactions were tested with a one-way analysis of variance (ANOVA) using the general linear model procedure according to SAS Institute Inc. (1998). When analyses of variance were significantly different at $P < 0.05$ ($\alpha = 0.05$) the means were separated by least significant difference (LSD) using the P Diff test (Steel and Torrie, 1997) in SAS (1988).

Each day was divided into four periods of six hours each to conduct the statistical analysis of feed and water consumption as well as the water to feed ratio. Period one was from 00:00 to 06:00 h, period two was from 06:00 to 12:00 h, period three was from 12:00 to 18:00 h, and period four was from 18:00 to 00:00 h.

2.6.1. Feed and Water Consumption Analysis

The dependent variables: feed intake, water consumption and water to feed ratio were analyzed with the independent variables: treatment, chamber, day, period, the interaction between treatment and day, and between treatment and period as the sources of variation (Table 2.2). For Model A the trials were considered as blocks, and a one-way analysis of variance design was followed were the temperature treatments were the main effect.

Table 2.2. Experimental design for feed and water consumptions during Model B (trial 1) and Model C (trial 2).

Source of variation	df
Temperature treatments (T)[1]	3
T x Chamber (C)[2] (error)	4
Days (D)[3]	13
T x D	39
T x C x D (error)	52
Periods (P)[4]	3
T x P	9
P x D	39
T x P x D (error)	117
Total	279

[1]Four temperature treatments per trial. Trial 1:control, diurnal cooling, nocturnal cooling and thermal conditioning. Trial 2: control, diurnal cooling, nocturnal cooling and commercial.
[2]Eight chambers, two per treatment.
[3]Feed and water consumption from d29 to d42
[4]Days were divided in four periods of 6h. Period 1: 0-6h; period 2: 6-12h; period 3: 12-18h and period 4: 18-0h.

2.6.2. Live Weight Performance

Live weight performance was analyzed in one-way analysis of variance by taking the individual bird final body weights (BW) per chamber as dependent variables and by taking temperature treatments as the independent variables. In order to determine the effects on weight gain and feed conversion, treatments, chamber, week and the interaction between chamber-treatment and week-treatment were used (Table 2.3). Weight gain and feed conversion (feed/gain) were calculated based on the weekly body weight of 50 birds per chamber (30 birds chosen at random plus the 20 selected labeled birds per chamber).

Mortalities were analyzed by applying χ^2 (Chi- square) analysis with the CATMOD procedure of SAS software (SAS, 1998).

Table 2.3. Experimental design for BW gain in Models B and C

Source of variation	df
Temperature treatment (T)[1]	3
T x Chamber[2] (error)	4
Week (W)[3]	5
T x W (error)	15
Total	27

[1]Four temperature treatments per trial. Trial 1:control, diurnal cooling, nocturnal cooling and thermal conditioning. Trial 2: control, diurnal cooling, nocturnal cooling and commercial.
[2]Eight chambers, two per treatment.
[3]Birds BW were found weekly during the six weeks (42d) of each trial.

2.7. Temperatures at bird level

The temperature that the broiler experiences can be quite different from airspace temperature in the barn, especially during the last two weeks of rearing. Although the matter was tangential to the main purpose of this work, given the possible significance for further studies, a preliminary research on that matter was carried out. The goal was to take initial steps towards finding an intelligent sensor to express in physical terms what the birds may experience. In order to accomplish this goal, a multiplicity of assumptions, calculations and measurements were taken and are discussed in the following sections. Needless to say, the validity of these preliminary assumptions and calculations should be thoroughly examined as these matters take center stage in future investigations.

Measuring the internal temperature of a black bottle (1-L) filled with water in the vicinity of the bird (15 cm from the floor) appears to be a reasonable indicator of the bird's microclimate temperature. When air flows over a surface, a boundary layer, or stagnant film of still air, adheres to a surface and acts as insulation (Simmons *et al.*, 1997). In the case of the broiler, the air insulation plus the insulating feathers create a microclimate around it, and as a result, it is difficult to measure the real temperature

perceived by the broiler. The results obtained from the black bottle temperature analyses combined with the heat stress indexes (HSI) (Section 2.7.2) are parameters that can be used to explain a) the effects of hot temperatures on a bird's performance, b) how the bird responds to the temperature fluctuations surrounding it and c) contribute to the improvement in bird's comfort. In addition, an analysis of the data may lead to a possible explanation of how birds can adjust their metabolism to environmental temperature fluctuations.

Emmanuel (2001) used a black bottle to measure the microclimate temperature at the birds' level. He measured the surface temperature of the bottle using a non-contact infrared thermometer. He assumed that the surface temperature of the bottle represented the effective ambient temperature due to the capacity of the black bottle to absorb radiant heat.

During this project, the temperature of the bird space was measured using the same type of black plastic water bottle. The bottle was located in the middle of each chamber at bird level. However, rather than measuring the surface temperature of the bottle, a thermistor was inserted in the bottle and connected to the data acquisition (I/O data logger) control computer. The working assumption was that the thermal mass of a bottle filled with water (1 kg) may serve as a rough approximation of the thermal mass of a broiler and if such is the case, then changes in the temperature of the bottle may serve as a rough indicators of the birds' experience of microclimate temperature; or at least, as better indicators of this temperature than chamber temperature.

2.7.1. First-Order Systems (Time Constant)

It is necessary to understand the behavior of a system for measuring temperatures such as a thermistor, before analyzing the temperature readings provided by the system. A series of guiding hypotheses were developed on the basis of the

characteristics of first-order systems used in mechanical measurements. Beckwith *et al.*, (1982) affirmed that certain temperature-measuring systems tend to behave according to first-order rules. The equation of the first order system is the basis for the equations of the step-forced and the harmonically excited first-order systems, which originated from Newton's second law. It be written, as described by Beckwith *et al*, (1982), as follows:

$$\zeta \frac{ds}{dt} + ks = F(t) \qquad (2.1)$$

Where (Note: In all these equations),

t = time,

s = displacement,

ζ= the damping coefficient,

k = the deflection constant, and

F_0 = the amplitude of the constant input force, (temperature in this project).

2.7.1.1. Step-Forced First-Order System

The response of the bottle temperature, as described by a time constant to a change in ambient temperature, bears particular notice. Heated/cooled bulk masses behave as first order dynamic systems.

In Equation (2.1) it is assumed that

$$F(t) = 0, \text{ for } t<0$$

and

$$F(t) = F_0, \text{ for } t \geq 0$$

For temperature (force equilibrium) on the connecting element (which is assumed to be mass-less)

$$\zeta \frac{ds}{dt} + ks = F_0 \qquad (2.2)$$

Then resolving Equation (2.2) by integration, to solve *ds /dt,* the following results:

$$\frac{F_0 - ks}{F_0 - kS_A} = e^{-kt/\zeta} = e^{-t/\tau} \qquad (2.3)$$

Where $\tau = \frac{\zeta}{k}$ is known as the *time constant.*

In order to convert Equation (2.3) into Equation (2.4) Beckwith *et al*, (1982) assumed that "a first order system represents any dynamic condition wherein the elements are essentially mass-less, the displacement constraint is linear, and a significant viscous rate constraint is present." Using this information, Equation (2.3) can be expressed in terms of temperature as:

$$T = T_\infty + [T_A - T_\infty]\, e^{-t/\tau} \qquad (2.4)$$

In these equations,

T = the temperature at any time '*t*',

T_∞ = the limiting or higher temperature of the heating process as $t \rightarrow \infty$,

T_A = initial temperature of the process at $t = 0$, and

τ = time constant for that specific process.

If the magnitude of a time constant of one hour is substituted by t =1h in Equation (2.4), then

$$T = T_\infty + (T_A - T_\infty)\,(0.368).$$

From this, one concludes that (1- 0.368), or 63.2 % of the physical process has occurred as shown in Figure 2.11 where the response of the first order system is subject to a step function (T_A =1 to T_∞ =5) for a progressive process in time (Beckwith *et al.*, 1982). In other words, if the ambient temperature changes 1°C, then the water bottle temperature would change 0.63°C after one time constant.

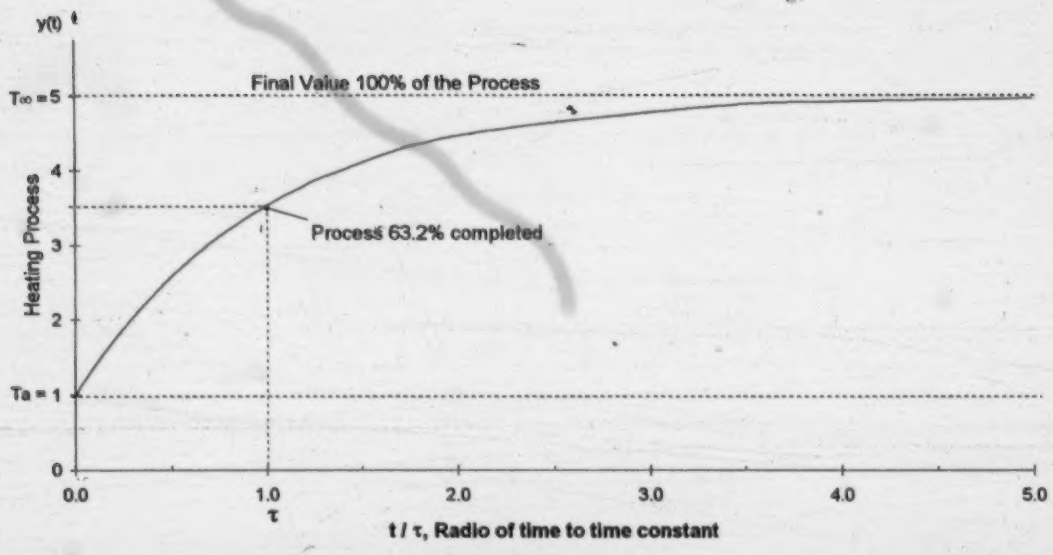

Figure 2.11. Response of a first- order system subject to a step function for a progressive process, wherein the action is an increasing function of time. Adapted from Beckwith *et al.*, (1982).

The response time is determined by the time constant 'τ', where a larger τ value gives a slower response. In a separate test from the two trials, one of the time constants for the black bottle full of cold water, T_A= 2 °C, was determined by leaving the bottle for one day in a room at low ventilation rate (free convection) and a constant ambient temperature of T_∞= 19.5 °C (Equation 2.4). The step change or step function was the sudden temperature increment from 2 °C (temperature of the water) to 19.5 °C (ambient temperature). The temperature of the water inside of the bottle was measured the same way as during the experiment, by inserting a thermistor into the bottle. A HOBO data logger and temperature sensor (Onset Computer Corporation, Bourne, MA) with accuracy of ±0.5 °C at 20 °C was used for this purpose. In Figure 2.12, the ambient and bottle temperature curves are shown as well as the exponential temperature curve of the bottle.

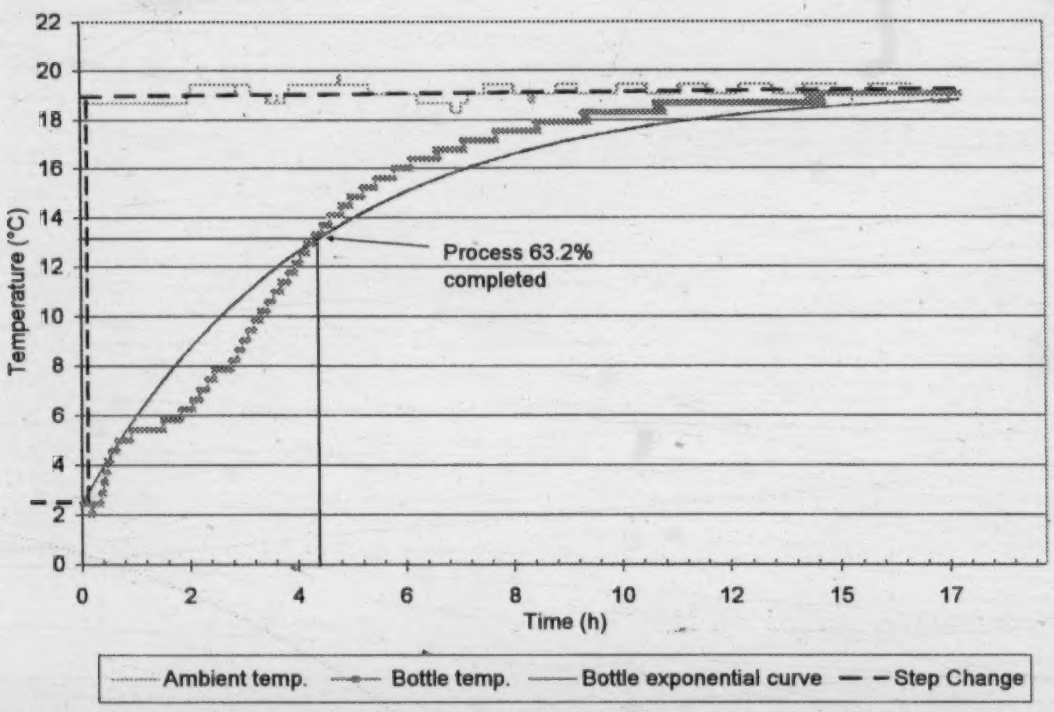

Figure 2.12. Bottle temperature sensor response to a step change in ambient temperature under low air speed conditions (free convection). The exponential curve from applying a time constant of 4.4 h (63.2% of the heating process) is shown.

In Figure 2.12, the bottle temperature curve and the exponential curve are shown after applying the time constant equation to the bottle temperature values. The first time constant for the black water bottle under low air speed conditions (free convection) was found with Equation (2.4) as follows:

The temperature corresponding to the 63.2% of the water bottle heating process, selected from the step change of 2 °C to 19.5 °C, was T = 13 °C after 4.4 h which represents T in Equation (2.4). From Figure 2.12 the time value that corresponds to the y-axis of T (°C) = 13 and the x axis is the time x = 4:25 min that represents a time of t = 4.4 h. Replacing those values in Equation (2.4):

$$13°C = 19.5°C + [2\ °C - 19.5°C]\ e^{-4.4/\tau}$$

$$\ln\left(\frac{6.5}{17.5}\right) = \ln e^{-4.4/\tau}$$

$$-0.99 = -4.4/\tau$$

$$\tau = 4.4 \text{ h (Bottle time constant at low air velocity)}$$

The parameters of a possible range for the bottle time constants under different temperature and low ventilation intervals are indicated by the time constant of 4.4 h and a time constant obtained from the same bottle under high airspeeds or forced convection. The two time constants were used here as indicators of whether the time constant found from the bottles located inside of the AEPEC's chambers were typical.

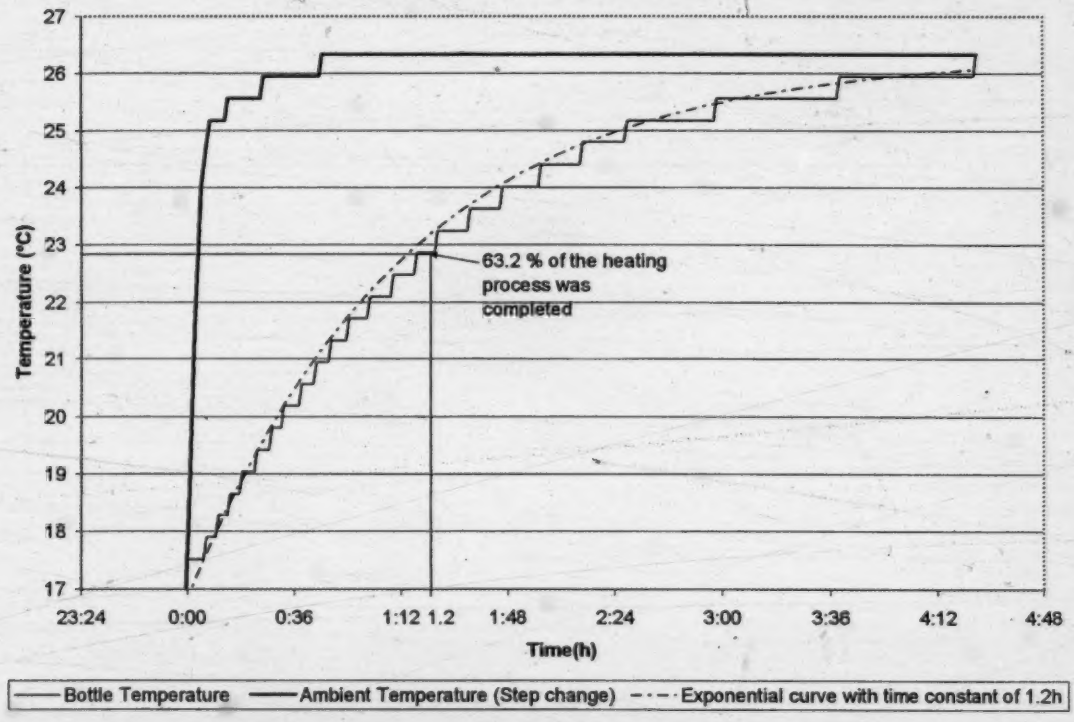

Figure 2.13. Bottle temperature response to a step change in ambient temperature under high air velocity conditions (forced convection).

The second time constant from a black bottle was determined using a plant growth chamber Conviron CMP 3244 (Winnipeg, MB). The temperature step-change

applied was from T_A = 17 °C, T_∞ = 26.4 °C. From Figure 2.13, 63.2 % of the process was completed at T= 22.9°C that corresponded to a time t = 1.2h. The cooling system utilized by the plant growth chamber to control its temperature consisted of a fan that provided constant flow ventilation and relatively high air speed (forced convection) of ~0.5 m/sec measured with a VelociCalc Portable Air Velocity Meter, (TSI, St. Paul, MN). Making use of Equation (2.4), the second time constant was calculated given a value of τ = 1.26 h.

After determining the possible range of time constants for the bottle, in a step-forced first-order system under two different convective conditions (forced convection and free convection), the next step was to obtain the information required to find the bottle's time constant during the treatments. The temperature curves applied during the treatments followed a sinusoidal curve that can be associated with a harmonically excited first-order system.

2.7.1.2. Harmonically Excited First-Order System

The base equation for the harmonically excited first-order system is derived from the step-forced first-order system described in equation (2.1). To obtain the harmonically excited first-order system equation Beckwith *et al.*, (1982) stated that in equation (2.1) the function can be replaced by:

$$F(t) = F_0 \cos \Omega t$$

or

$$\zeta \frac{ds}{dt} + ks = F_0 \cos \Omega t \qquad (2.5)$$

Where:

F_0 = the amplitude of the forcing function (heating and cooling), and

Ω = the circular frequency of the forcing function in rad/s.

After further calculations and assumptions made by Beckwith *et al.*, (1982) the solution for Equation (2.5) can be presented as follows:

$$\frac{T}{T_s} = \frac{\cos(\Omega t - \phi)}{\sqrt{1+(\tau\Omega)^2}} \tag{2.6}$$

where:

T = temperature (magnitude) of the applicable process,

T_s = static deflection that would occur during the process,

ϕ = the phase lag = $\tan^{-1}\Omega\tau = \tan^{-1}\frac{2\pi}{\mathcal{T}}\tau$, and (2.7)

$\mathcal{T} = 2\pi/\Omega$ = the period of excitation cycle in h.

The phase lag ϕ value is the phase lag between the ambient temperature and the bottle temperature curves as shown in Figure 2.13. A temperature sensor inside a chamber subjected to harmonically variable temperatures (input) is an example of a harmonically excited first-order system.

The time constant for the control treatment temperature curve can be expressed by a harmonically excited first- order system found using Equation (2.7) and shown in Figure 2.13. The phase lag (ϕ) between the ambient and bottle temperature assumed to be ϕ =1.9h was used to find the bottle time constant. It is important to stress that the differences in time or phase lag between the ambient temperature and the bottle value is based on the ambient temperature curve assume at water bottle height.

Calculating the time constant based on the phase lag:

Time lag ϕ = 1.9 h, or ϕ = 1.9 h x 360 / 24h =28.8° (angle)

Finding time constant from (2.7)

$\tau = \mathcal{T} \tan\phi/2\pi$

$= (24h \times \tan 28.8°) / 2\pi$

$\tau = 2.1\ h$

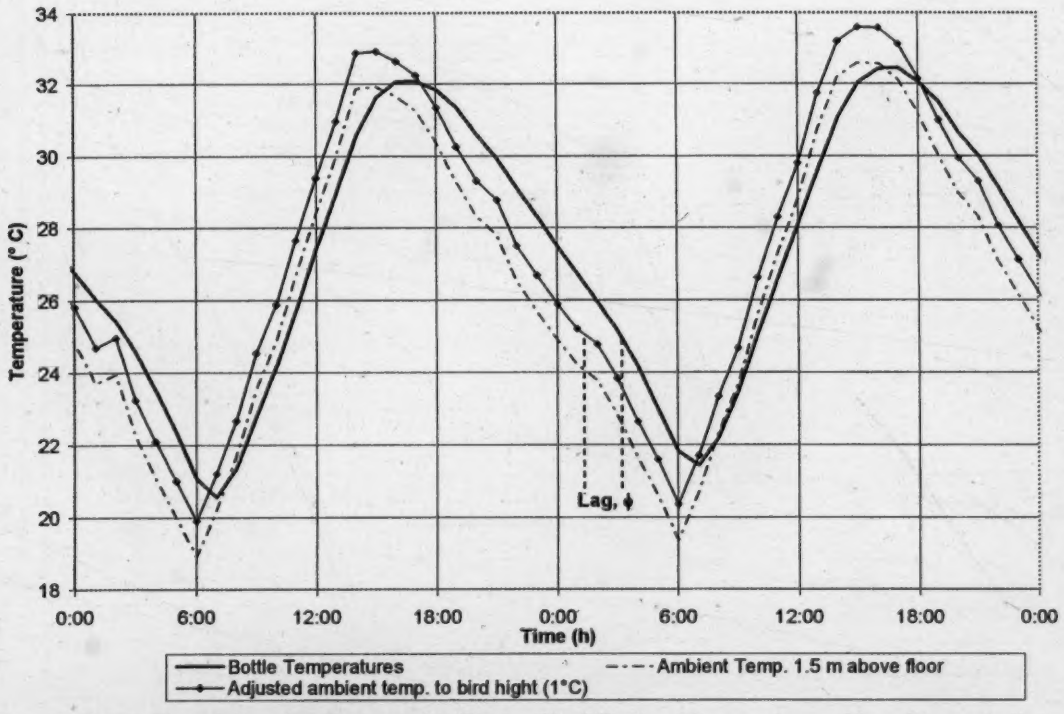

Figure 2.13. Example of a harmonically excited first order system. Hourly control treatment temperatures (d37 to d38).

The time constant (τ) of 2.1h for the bottle may explain the bird response (final body weights, FCR and mortality) to cyclic ambient temperatures.

2.7.2. Heat Stress Indices

Yousef (1988) pointed out that various indices have been developed to measure environmental thermal stress in animals, i.e. wind-chill factor, THI (temperature-humidity index), WBGT (wet-bulb-globe-temperature index), but a complete index that includes climatic, biotic and physiological factors has not been found.

In order to evaluate, in a simple way, the effect of high temperatures (climatic factor) on bird performance, heat stress indices (HSI) were found for all chambers using hourly temperature data. The formula applied to find these values was used by Emmanuel (2001) to estimate the effect of temperature on broiler performance. The formula is:

$$HIS = \Sigma ((T_A - T_R)^* \text{ bird age in days or hours}) \quad (2.3)$$

This index assumes that a high difference in temperatures between chamber (ambient, T_A) and the commercial (T_R) becomes more critical as the birds become older, representing the physiological factor (bird age in days) that Yousef (1988) mentioned.

3. Results and Discussion

The analysis yielded very interesting results. Thousands of collected data points were analyzed through the various statistical models and were divided into six sections which were: chambers performance, feed and water consumption, live weight performance, mortality, economic analysis and temperature at bird level.

3.1. Chambers Performance

The thermistors that were used to record the ambient temperature in each chamber were calibrated at the end of the second trial. It was not possible to do the calibration before the experiment due to the short time available to set up the chambers. The calibration was made using two mercury thermometers (Brooklyn Thermometer Company Inc., Farmingdale, NY) that have been tested with standards certified by the American National Bureau of Standards. The thermistors were tested at three different temperatures using containers filled with cold, warm and hot water into which the thermometer and a thermistor were submerged adjacent to each other. These data

allowed the calculation of all the thermistor accuracies. It was found that all of the thermistors had an offset of ~1°C. The accuracy of the thermistors were found to be ± 0.2 °C.

The temperature readings measured in each chamber were compared to the target or desired temperatures (input temperatures) in order to find how stable the chambers were in maintaining the desired temperature required for each treatment. The corresponding target temperature and the hourly temperature data were subtracted and averaged.

Table 3.1. Mean set point-ambient temperatures differences and standard deviations values in °C for all chambers from 29 to 42 d.

Chamber	Trial	Temperature Treatment	Mean Difference (°C)	Std. Dev. (°C)
1	1	Control[1]	-0.1	0.9
	2	Nocturnal Cooling[2]	0.2	1.0
2	1	Diurnal Cooling[3]	0.0	0.9
	2	Commercial[4]	0.2	0.7
3	1	Nocturnal Cooling	-0.1	1.2
	2	Control	0.1	0.9
4	1	Thermal-conditioning[5]	-0.1	0.9
	2	Diurnal Cooling	0.1	0.8
5	1	Thermal-conditioning	-0.1	0.9
	2	Diurnal Cooling	0.1	0.9
6	1	Nocturnal C.	0.1	1.1
	2	Control	0.0	0.8
7	1	Diurnal Cooling	0.1	0.9
	2	Nocturnal C.	0.2	1.1
8	1	Control	0.1	0.9
	2	Commercial	0	0.9

[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[3]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[4]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).
[5]Thermal-conditioning treatment: control treatment except that temp. in d5 was increased to 40 °C.

To determine the accuracy of the system temperature control, the average temperature and standard deviation were calculated from the resulting difference values found for each chamber (Table 3.1). The average of the temperature differences in the

chambers was on the range of - 0.1 to 0.2 °C, with standard deviations between ± 0.8°C to ±1.2°C, thus indicating approximately the accuracy and response of the heating system.

3.2. Feed and Water Consumption

Graphical examples of the feed and water consumption readings in a period of time are shown in Appendix B.

3.2.1. Model A

Table 3.2. Overall feed and water consumption per bird from 29 to 42 d of age and bird performance.

Model	Treatment	Total feed intake 0 - 42 d (g/bird)	Feed intake (g/bird)	Water intake (mL/bird)	BW (g)	BW SEM (g)	CV of Final BW (%)	Product per unit area (kg/m^2)
A	Control[1]	3721	2075	3774	2062	45	12.4	34.0
	Diurnal Cooling[2]	3792	2110	3870	2106	63	12.7	34.9
	Nocturnal Cooling[3]	3810	2129	3808	2095	64	12.4	34.6
	Mean	3774	2105	3817	2080			34.5
B	Control	3719	2130	3752[a]	2025	22	12.2	33.7
	Diurnal Cooling	3785	2160	3676[a]	2047	23	12.5	34.5
	Nocturnal Cooling	3774	2163	3794[ab]	2033	22	12.4	34.1
	Thermal conditioning[4]	3828	2203	3888[b]	2046	22	12.8	34
	Mean	3777	2164	3778	2038			34.1
C	Control	3723	2020	3796	2057	45	12.6	34.4
	Diurnal Cooling	3799	2060	4045	2099	45	12.9	35.2
	Nocturnal Cooling	3846	2095	3822	2085	45	12.4	35
	Commercial Temperature[5]	3866	2110	4024	2120	45	12.4	35.9
	Mean	3809	2071	3922	2090			35.1

[a,b,c,d] Means, within each column, and within models with no common letter are different (P<0.05).
[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Thermal-conditioning treatment: control treatment except that temp. in d5 was increased to 40 °C.
[5]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).

In this model, in order to compare the common treatments between trials it was assumed that the differences in external (ambient) temperature between the trials (January to March) were not significant. Furthermore, it was assumed that the temperature curves were the same for the common treatments in both trials.

Water consumption between treatments due to the main effect of temperature, during the last two weeks of rearing, was found not to be different (P= 0.34) (Table 3.2). However, the water consumption interaction between period and treatment was different (P=0.02).

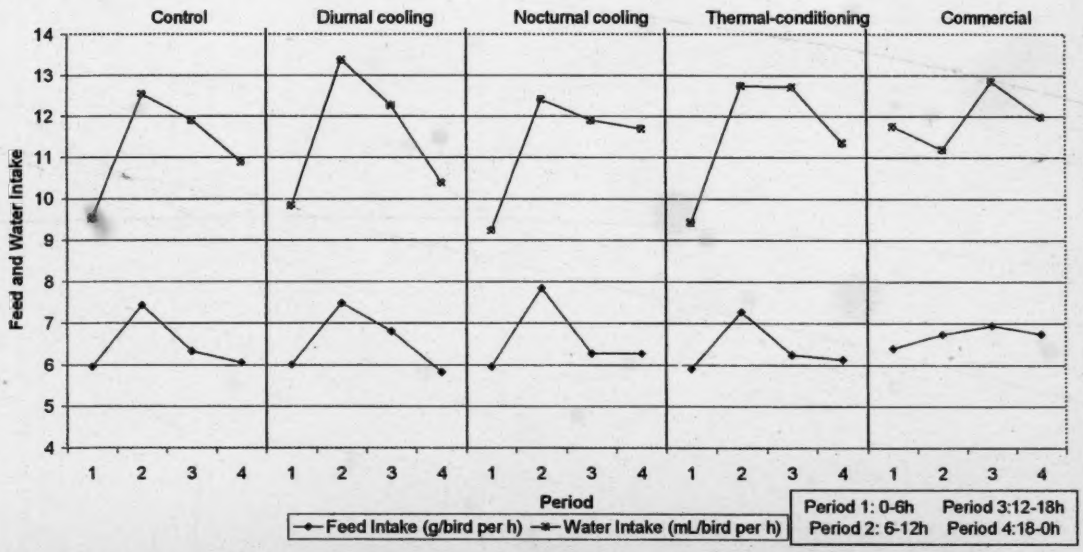

Figure 3.1. Hourly feed and water consumption (29-42 d) per bird by periods. The curves for control, diurnal cooling and nocturnal cooling treatments correspond to Model A, the thermal conditioning correspond to Model B, and the commercial temperature Model C.

Overall, the period with the highest feed and water consumption was period 2 (06 to 12 h) for all the treatments. The high feed intake rates in period 2 were followed by period 3 (12 to 18 h), period 4 (18 to 00 h) and finally by period 1 (00 to 06 h) (Figure 3.1 and Table B.5 in Appendix B). The morning time or period 2 was prior to the temperature peak being reached. This could be a factor in feed and water consumption

patterns being higher since birds are more likely to eat before the temperatures increase (May et al, 2000).

Table 3.3. Water to feed ratios (mL:g) by periods for models A, B and C.

Treatment	Period	Model A (mL:g)	Model B (mL:g)	Model C (mL:g)
Control	1	1.59	1.42	1.76
	2	1.70	1.76	1.64
	3	1.90	2.01	1.79
	4	1.80	1.66	1.94
Diurnal Cooling	1	1.61	1.34	1.89
	2	1.78	1.86	1.69
	3	1.80	1.73	1.87
	4	1.82	1.73	1.90
Nocturnal Cooling	1	1.58	1.46	1.70
	2	1.59	1.66	1.52
	3	1.92	2.01	1.84
	4	1.96	1.86	2.05
Thermal conditioning	1		1.49	
	2		1.69	
	3		1.96	
	4		1.78	
Commercial	1			1.86
	2			1.84
	3			1.85
	4			1.91
SEM		0.05	0.07	0.06
P		0.03	0.012	0.016

[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Thermal-conditioning treatment: control treatment except that temp. in d5 was increased to 40 °C.
[5]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).
SEM - Standard error of the mean
Significant different at $P<0.05$

For the water to feed ratio, the interactions by treatments were not different (P=0.92). However, the interaction between water to feed ratio, period and treatment was different (P=0.03). The highest values for ratios, shown in Table 3.3, were for periods 4 (1.96 mL/g) and 3 (1.92 mL/g) during the nocturnal cooling treatment. This indicates that birds consume more water relative to feed during and after the periods of highest temperatures. The lowest ratio from the interaction between treatment and

period was during period 1 (00 -06 h) when the temperatures were the lowest. The water to feed ratio that is sought after in the industry is about 1.7 mL/g (Emmanuel, 2001).

3.2.2. Model B

The average total feed consumption (Table 3.2), during the last two weeks of rearing, were not different (P= 0.82) between treatments. The interaction between period and treatment was different (P=0.01) demonstrating a relationship between the temperature fluctuations and the birds response at each period of the day (Figure 3.1). Like Model A, the period with the highest feed and water consumption was period 2 for all the treatments. The feed intake rates during period 2 were followed by those in periods 3, 4 and finally by period 1 (Figure 3.1 and Figure B.5 in Appendix B). The temperature peak occurring in period 3 were a factor in the higher feed and water consumption patterns in period 2. This was expected since birds are assumed to eat at the lowest temperatures.

For water consumption, treatments were different (P<0.05). In Table 3.2, the diurnal cooling treatment had the lowest mean total consumption of 3676 mL/bird from 29 to 42 d. The thermal conditioning treatment had the highest water consumption of 3,888 mL/bird from 29 to 42 d (Table 3.2). The difference of the thermal conditioning treatment could be as a result of the bird's response after the thermal conditioning at day 5. However, the water intake by the birds from the nocturnal cooling treatment was not different from the values of the thermal conditioning treatment.

For the water to feed ratios, the interaction between treatments was not significant (P =0.16) (Table 3.3). For the water to feed ratio the interactions between day and period was significant as well as the interaction between period and treatment (P=0.012) (Table 3.3).

Table 3.4. Overall feed conversion

Model	Treatment	Feed Conversion (g:g)
A	Control[1]	1.79
	Diurnal Cooling[2]	1.75
	Nocturnal Cooling[3]	1.78
	P	0.22
	SEM	0.011
B	Control	1.79
	Diurnal Cooling	1.75
	Nocturnal Cooling	1.75
	Thermal conditioning[4]	1.85
	P	0.40
	SEM	0.044
C	Control	1.78
	Diurnal Cooling	1.76
	Nocturnal Cooling	1.80
	Commercial[5]	1.82
	P	0.70
	SEM	0.034

SEM - Standard error of the mean
Significance level stated at $P < 0.05$
[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Thermal-conditioning treatment: control treatment except that temp. in d5 was increased to 40 °C.
[5]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).

The highest values for the interaction between period and treatment for the ratios, shown in Table 3.3 and Appendix-Figure B.5, were for period 3 where control and nocturnal cooling showed a 2.01 mL/g ratio. This indicated that water intake was higher than the feed consumed during and after the temperatures reached the highest values. For all four treatments the lowest ratio resulted from the interaction between treatment and period during period 1 (0 to 6h) when the temperatures were the lowest.

3.2.3. Model C

For this model, the feed consumption between treatments during the last two weeks of rearing, was found not to be different (P= 0.86) with an overall mean of 2071 g/bird (Table 3.2).

The water consumption between treatments during the last two weeks of rearing were also found not to be different (P= 0.27) with an overall mean of 3922 mL/bird (Table 3.2). As well, water to feed ratios were not different between treatments (P=0.38) (Table 3.2). This could represent a constant relationship between feed and water consumption in all treatments. However, as with the other models, the interactions between period and treatment were significant as well as the interactions between day and period (Figure 3.1 and Table B.5 in Appendix B). The results suggest that birds eat and drink at different rates based on the temperatures during the day.

Feed consumption per period during the commercial temperature treatment was consistent in comparison with the other three treatments during the four periods as is shown in Figure 3.1. The period with the highest feed and water consumption was period 2 (06 to 12 h) for all the treatments except during the commercial temperature treatment. In that treatment the feed intake did not show major fluctuations and the water intake was the highest in period 3 and the lowest during period 2.

The feed intake rates on period 2 was followed by period 3, then 4 and finally by period 1 (Figure 3.1 and Appendix B). Like Model B, the feed and water consumption peak in period 2 likely occurred because of the temperature peak in period 3. Feeding and water consumption patterns were higher since birds are assumed to eat at the lowest temperatures. For the commercial temperature treatment, the feed consumption did not peak during a certain period of time as in the other treatments, most likely

because of the constant temperature during the day. However, the mean of the feed consumption in the other treatments reached equilibrium throughout the day.

The water to feed ratio interaction between period and treatment were different (P=0.016) (Table 3.3). The highest values for ratios, shown in Table 3.3 and Figure B.6 in Appendix B, were for periods 4 where nocturnal cooling showed a 2.05 mL/g ratio.

From the three different models, it is possible to conclude that temperature fluctuations have an effect on feed and water consumption in the short term (hourly periods) but did not have a clear direct effect in the long term (days and weeks).

3.3. Live Weight Performance

The birds live weight performance is shown in Table 3.2, Table 3.4 and Appendix B. In Model A, the final body weights (P=0.79) with an overall mean of 2080 g/bird and their coefficient of variance were not different between treatments (Table 3.2). These results demonstrate the similarity in uniformity of the response of the birds to different temperature regimes. As expected in Model A, BW gain and feed conversion between weeks were different (P<0.05) due to the differences between the birds' weekly growth rate. Taking treatments as independent variables, weight gain (P=0.51) and feed conversion (P=0.22) results were not different (Table 3.4).

For Models B (P = 0.83) and C (P=0.92), BW gain between treatments were not different using the interaction between chamber and treatment as an error term. The results for Model B (P= 0.40) and Model C (P=0.77) showed no differences for feed conversion between treatments (Table 3.4). Differences between weeks have not been a relevant parameter in this case. The analysis of variance did not show differences (P>0.05) in final body weights where the overall means for Model B was 2038 g/bird and

2090 g/bird for Model C (Table 3.2). The coefficients of variance did not show variations demonstrating no differences in flock uniformity.

The lack of differences between final body weights (BW), feed consumption and water consumption in both trials are an indication of an "acclimatization" of the birds to their environment. Yousef (1985) describes acclimation as "a physiological change, occurring within the lifetime of an organism, which reduces the strain caused by experimentally induced stressful changes, in particular, climatic factors." Another term that can describe the birds' response to the temperatures fluctuations is 'habituation' as a "reduction of responses to or perception of repeated stimulation." It is clear that for all the temperature treatments the broilers went through a common process of acclimation or habituation of their environment given similar results.

The bird acclimation that occurred in this project can be related to other research projects where temperatures are a major factor on bird's physiological adaptation. For instance, the results found by Ain Baziz *et al.* (1996) suggest that an enhancement of fat deposition exists in broilers exposed to chronic heat. Their conclusion is based on the idea that under heat exposure the basal metabolism rate and the physical activity will be reduced, leading to more energy available for growth which is essentially stored as abdominal and subcutaneous fats. However, it is not certain that under cyclic high ambient temperature where the increase in fatness may often not be as great as under constant high temperature. Without a doubt, deposit lipids might be used for thermoregulatory purpose during the coolest part of the day (Ain Baziz *et al.*, 1996). Yahav *et al.*, 2001, affirm that one of the processes that improve thermo-tolerance during thermal challenges involves the modulation of heat production through reduction in plasma triodothyronine.

Further research has to be done to find the birds physiological adaptations such as fat body content, and changes in plasma components in relation to the high temperature fluctuations (heat stress) applied in this research.

3.4. Mortality

Mortalities (Table 3.5) (Appendix B) were analyzed by applying χ^2 (Chi square) analysis with the CATMOD procedure of SAS software (SAS Institute, 1998), between trials and within treatments taking again the three different comparisons. For Models A, B and C no differences were found due to treatments effects, for sudden death syndromes (SDS), ascites, oomphalitis, culled birds and all other diseases. SDS, ascites and oomphalitis were the most common diseases present during the project. For all of the models most of the culled birds occurred because of leg problems.

Table 3.5. The total percentage of mortality for all treatments from 0 to 42 d of age and the percent of mortality due to Sudden Death Syndrome (SDS), ascites, oomphalitis, culled (leg problems) and other causes.

Treatments	Marketable Birds (%)	Mortality (%)	Mortality due to:				
			SDS (%)	Ascites[3] (%)	Omphalitis (%)	Culled[4] (%)	Other[3,5] (%)
Control[1]	93.4	6.62	2.37	0.90	0.65	0.90	1.80
Diurnal Cooling[1]	94.1	5.88	1.72	1.23	0.65	0.82	1.47
Nocturnal Cooling[1]	94.0	6.05	2.04	0.98	0.65	0.65	1.72
P>Chi Sq		0.218	0.522	0.473	0.797	0.886	0.163
Thermal Conditioning[2]	92.8	7.19	2.45	0.82	0.82	1.63	1.47
Commercial [2]	94.9	5.07	2.12	0.33	0.16	0.65	1.80

[1]From four replicates - Model A
[2]From two replicates – Models B and C
[3]Included condemnation from processing plant
[4]Included birds culled because varus-valgus
[5]Other diseases are cellulitis, emaciation, hepatitis and pendulous crop

The condemnations at the processing plant for ascites, cellulitis, emaciation, varus-valgus and other less frequently occurring diseases such as hepatitis and pendulous crop were added to the mortality analysis taking into consideration that those birds were discarded from the processing line (Table 3.5).

3.5. Economic Analysis

The economic analysis was made using Chickcop, (1997). The parameters included in the analysis were the means of final body weights (BW), feed consumption, feed conversion rate (FCR), the mortality during the two trials and the condemnations in the processing plant. The values obtained from the analysis were margin over feed and chick cost, and break-even income (BEI). These values were used in a statistical analysis with SAS one-way analysis of variance. The two trials were analyzed separately taking the margin over feed and chick cost and BEI as dependent variables for the four treatments in each trial.

In Table 3.6, the results shown are not different between treatments. The results for trial one (Model B) show no differences (P= 0.95) in margin over feed and chick cost between treatments as well as no differences in the BEI (P=0.95). The results for trial two (Model C) did not show differences for margin over feed and chick cost (P=0.89) and for BEI (P=0.92).

The results are indicative of how the costs of raising broilers chicken can be reduced without affecting the bird's final performance. Energy costs were not considered and were assumed to be similar between treatments. This economic analysis further supports the results obtained from the bird performance and mortality analysis where no differences were found.

Table 3.6. Effect of temperature treatments on the costs[1] of production.

Trial	Temperature treatment	BW (g)	FCR (g/g)	Mortality (%)	Condemns (%)	Starter 1-3 wks (g/bird)	Grower 4-6 wks (g/bird)	Margin over Feed[2] and Chick[3] cost ($/kg)	Break even income[4] ($/kg)
1	Control[5]	2027	1.78	5.56	1.21	818.2	2870.2	0.37	0.91
	Diurnal cooling[6]	2051	1.76	3.27	2.39	815.8	2930.1	0.37	0.90
	Nocturnal cooling[7]	2035	1.75	4.90	1.05	824.1	2926.7	0.38	0.90
	Thermal conditioning[8]	2052	1.85	5.88	1.04	827.5	2973.3	0.36	0.92
2	Control	2059	1.79	5.07	1.21	918.3	2805.2	0.38	0.89
	Diurnal cooling	2102	1.77	4.41	1.37	948.9	2850.0	0.39	0.89
	Nocturnal cooling	2090	1.81	4.74	0.86	943.3	2902.6	0.38	0.90
	Commercial[9]	2123	1.82	3.76	1.36	971.2	2895.3	0.38	0.90

[1]Simulation of 50,000 quota unit production cycles @ 100% utilization on an 8 wk cycle
[2]Feed prices: Starter $284/T; Grower $256/T
[3]Chick price of $0.53/chick
[4]Total cost per kg raised before depreciation and financing
[5]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[6]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[7]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[8]Thermal-conditioning treatment: control treatment except that temp. in d5 was increased to 40 °C.
[9]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).

3.6. Temperatures at Bird Level

The results from the treatments are a clear demonstration of the birds' adaptation to dramatic temperature fluctuations during hot weather. However, there is no clear explanation as to why there was a lack of differences between the bird's response to the treatments. In order to find a possible answer, the temperatures collected at bird level (via the black water bottle) were analyzed. The following sections are possible explanations from the physical point of view of how the birds perceived a similar environment for each treatment.

The first step was to define how the water bottle responded to the ambient temperature changes. To do this, two time constant values based on low air speed and high air speed were determined as described in section 2.7. After finding the time constants at low air speed (free convection) of 4.4h and at a high air speed (forced convection) of 1.3h, it was necessary to find a time constant that linked the sinusoidal temperature curves (ambient and bottle) obtained from one of the treatment (as was described in section 2.7.1.2). These results will provide an idea of how the birds respond to their surrounding environment and provide a possible time constant of the birds.

The second step was to link the time constant with the sinusoidal temperature curves obtained in each treatment from both the ambient and the water bottle. Although the shapes of the two curves were relatively similar, the bottle temperatures did lag behind the ambient temperature measurements as shown in Figure 2.13 and in Appendix A. The lag between ambient and bottle temperature curves can be explained by the harmonically excited first-order system, a common physical model in measuring systems response (2.7.1.2).

In order to find a general time constant, a one day cycle was selected from the control treatment temperature (Figure 2.13). After the harmonically excited first-order systems equations were applied, using the temperature values of one cycle (d37 to d38), the time constant was 2.1h as described in section 2.7.1.2.

3.6.1. Relationship Between the Broiler Chickens Response and the Time Constants

In order to relate the variations in ambient and bottle temperatures with the bird response, two time constants values were found in section 2.7.1.1 (1.3h at high airspeed and 4.4h at low airspeed for a step change in ambient temperature) and the time

constant for the bottle in the chambers was found in section 2.7.1.2 to be 2.1h. The moving average was used as a tool to relate the temperature curves collected by the bottle in each treatment and the time constant.

3.6.1.1. Moving Averages

The first step to associate bird response and the time constant was to determinate the average temperature of each treatment curve by applying five moving averages. Moving averages of 1, 5, 10, 15, 20, and 24 h were calculated for each of the chambers hourly temperature curves. By plotting the resulting averages one can see that the moving averages showed a decreasing amplitude from the original curve. In fact, the 24h moving average curve is almost linear. Figure 3.3 shows the temperature moving average curves on day 35 for one of the control treatments in the second trial.

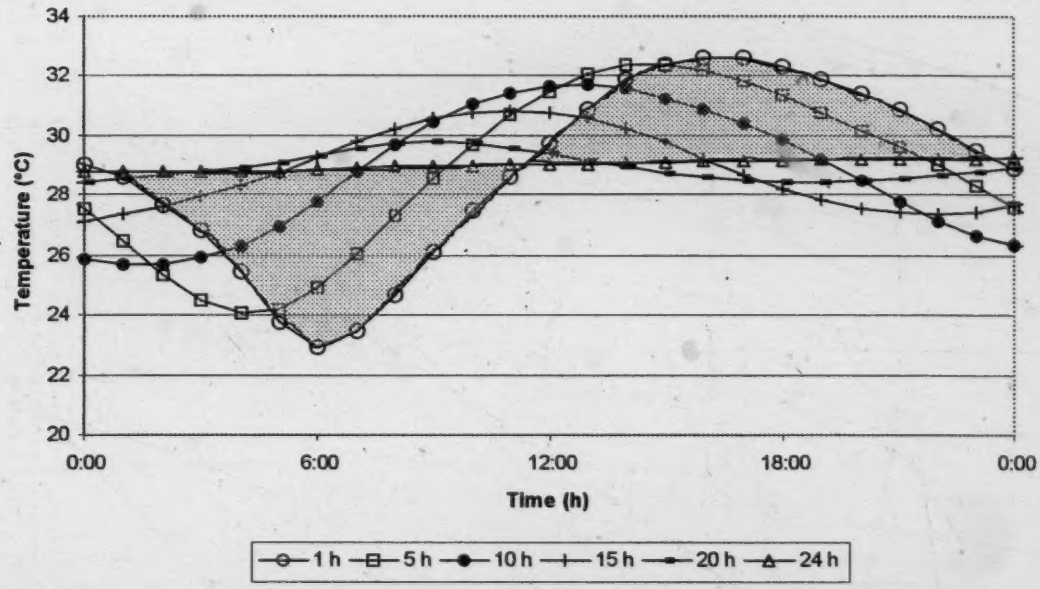

Figure 3.3. Temperature moving averages of 1, 5,10,15,20, and 24 h for the black water bottle in a control treatment on d 35. The area of the 1 h moving average is shaded.

The second step was to calculate the absolute mean temperature difference between the 24 h moving average curve and each of the other five moving average curves. This was calculated over a 14 d period (from 29 to 42 d of age).

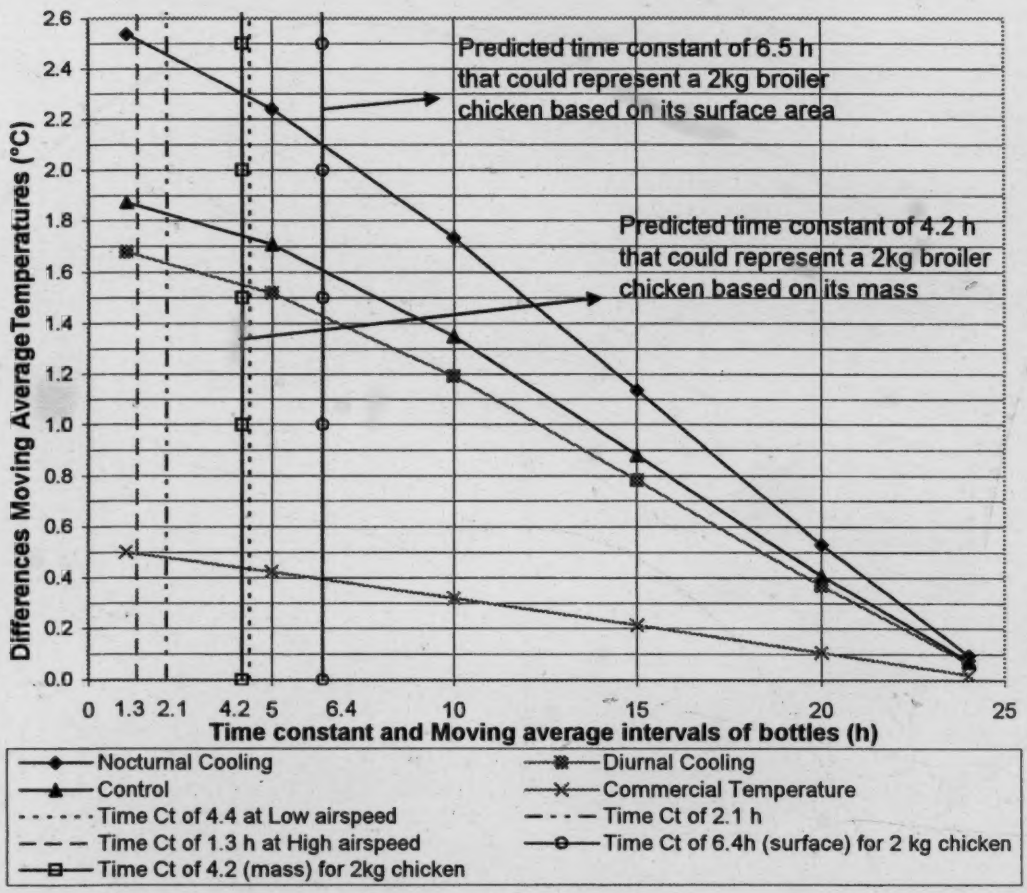
Predicted time constant of 6.5 h that could represent a 2kg broiler chicken based on its surface area
Predicted time constant of 4.2 h that could represent a 2kg broiler chicken based on its mass
Differences Moving AverageTemperatures (°C)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 1.3 2.1 4.2 5 6.4 10 15 20 25
Time constant and Moving average intervals of bottles (h)
Nocturnal Cooling
Diurnal Cooling
Control
Commercial Temperature
Time Ct of 4.4 at Low airspeed
Time Ct of 2.1 h
Time Ct of 1.3 h at High airspeed
Time Ct of 6.4h (surface) for 2 kg chicken
Time Ct of 4.2 (mass) for 2kg chicken

Figure 3.4. Mean absolute temperatures differences for 1, 5, 10, 15, 20 and 24 h from moving average temperatures and time constants.

Figure 3.4 shows the mean absolute temperature differences between the daily average temperature (24 h moving averages) and the time intervals of 1, 5, 10, 15 and 20 h used in the moving average curves for each treatment. The values for the 2.1h moving average represented the bottle time constant (63.2 % response to a step change of the bottle temperature). If in Figure 3.4, a vertical line is drawn intercepting the four

treatments lines at 2.1 h, the difference between the higher and the lower average temperatures difference treatments (nocturnal and commercial) is 1.98 °C. When one assumes a 2 kg mass bottle or double time constant of 4.2h (average weight of a 42 d old broiler chicken), the maximum difference between the nocturnal and commercial treatments is 1.85 °C (Figure 3.4). This suggests that the similarity in moving average temperatures for this time constant may reflect the similarity in bird response.

Between the diurnal cooling treatment and the control treatment values, shown in Figure 3.4, the difference is just 0.2 °C. Between the control and nocturnal cooling treatment in the 4.2 h moving average the difference is 0.6 °C. In the commercial temperature treatment, the moving averages are the lowest because the variation in temperature was minimal. Between the diurnal and nocturnal cooling treatments the difference in the temperature means was 0.8°C. These small differences in temperatures reflect the temperature that the birds likely perceived when the temperatures in the chambers were changing rather than the temperature measured by ambient temperature sensor. Broilers are homoeothermic animals, which mean that they can maintain their body temperature over a wide range of ambient temperatures (Appleby *et al.,* 1992). The birds could feel the same delay (time constant) in temperature fluctuations as the thermistor inside of the black bottle full of water due to their natural insulation, feathers, fat skin, and the content of water on their body; in essence the thermal mass protects the birds. Birds with twice the mass of the bottle may have a time constant of about 4.2 h that corresponds to a 2-L bottle. As was mentioned before, in Figure 3.4, the difference in absolute temperature at 4.2 h is just 1.85 °C, between the commercial temperature treatment curve and the nocturnal cooling curve, explaining the small differences in birds' performance. It is important to stress that if the air velocity would be increased in a chamber the response time would be

similar to the shorter time constant of 1.3h. Thus demonstrates that air speed is an important factor in bird's thermal comfort corroborating May *et al.*, (2000) results.

Another way to visualize the idea of how the average temperature fluctuations are related with time constants, moving average and bird performance is shown in Figure 3.5.

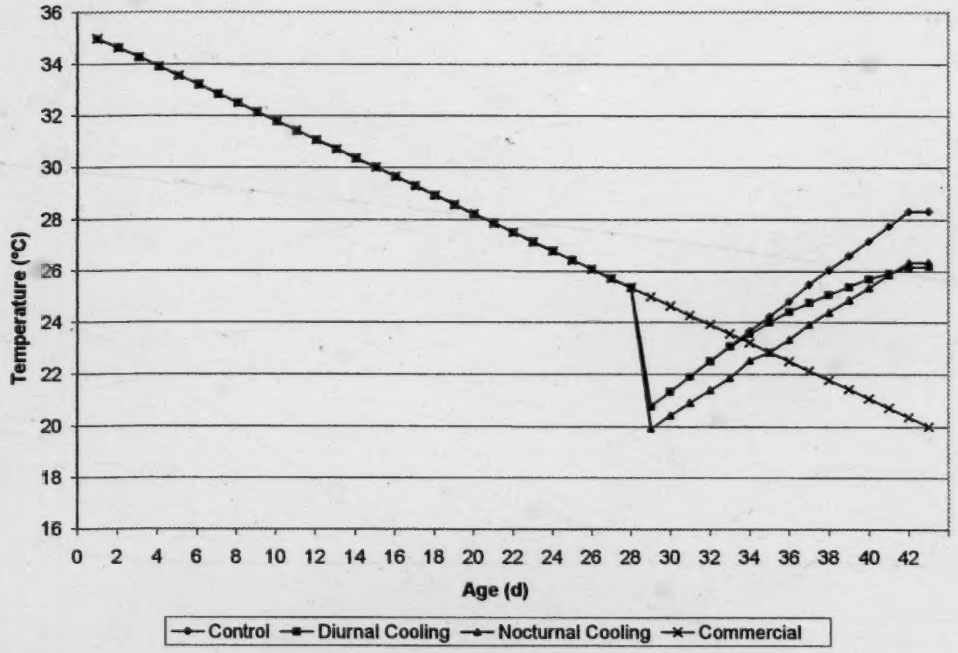

Figure 3.5. Daily temperatures average curves per treatment.

In Figure 3.5 the daily temperature average for each treatment is shown during the 42 d experiment. It is clear that during the last 14 days the means were different due to the temperature fluctuations; however those fluctuations are close (2 °C at maximum) from each other. The maximum 2 °C of variation between these treatments are similar to the differences in absolute temperature at a time constant of 4.2 h. The means show that if average daily temperatures are kept under 28 °C and above 20°C no effect on bird performance will occur.

3.6.1.2. Broiler Chickens Surface Area and Time Constant

An additional possible explanation to how the time constant can be interpreted is related to the bottles' surface area. If the time constant found in the previous section (based on mass) is associated with the surface area of the broiler versus the area of the bottle, the time constant would increase. The relation between total surface area and body weight of a chicken can be calculated by the Meeh equation (Curtis, 1981) as follows:

$$A = 8.2 * W^{0.71} \qquad (3.3)$$

Where A is the bird's surface area in cm^2 and W its body weight in g. The surface area of the 1-L bottle was estimated to be 0.059 m^2 and the surface area of a 2 kg broiler chicken (applying equation 3.3) is 0.181 m^2.

The ratio between the area of the 2 kg broiler chicken (0.181m^2) and the 1-kg (1-L) bottle surface (0.059m^2) areas is 3.07. To predict the time constant of a 2 kg broiler chicken, the time constant of the 1 kg bottle (2.1h) can be multiplied by the 3.07 ratio to find an approximate time constant of 6.4h (Figure 3.4). Further research will need to be conducted to analyze these values. Moreover, research should be conducted to determine a time constant for a broiler chicken.

3.6.2. Heat Stress Indices

Another method to evaluate bird response to heat stress is to calculate the heat stress indices for both the bottle and ambient temperatures. In Table 3.7, the values for hourly HSI values are shown. No differences in the bottle HSI values were found between treatments in the three models.

The noticeable difference between ambient HSI and bottle HSI values demonstrates the broilers may experience different temperatures than that of the temperature indicated by ambient thermistors. The black bottle temperatures showed

higher hourly HSI values. The bottle coefficients of variance in model A of 3.8 %, in model B of 7.7 % and in model C of 15.2 % are lower than the CVs of ambient HSI of 10.6, 9.6 and 52.8 %, respectively in Table 3.7. This suggests that the broiler body temperature fluctuations could be more uniform due to the bird mass, explained in sections 3.6.1 and 3.6.2 (time constant theory). The differences in CV can also be understood as the water (thermal mass) in the bottle reduces the noise or fluctuations in the ambient temperatures due to a time response delay (time constant) perceived by the thermistor inside the bottle.

Table 3.7. Hourly heat stress indices for the models from 29 to 42 d of age.

Model	Treatment	Ambient HSI (°C*h)	Bottle HSI (°C*h)
A	Control[1]	1635	2145
	Diurnal Cooling[2]	1321	2133
	Nocturnal Cooling[3]	1476	2009
	CV (%)	10.6	3.8
B	Control	1563	2187
	Diurnal Cooling	1272	2119
	Nocturnal Cooling	1419	1896
	Thermal Conditioning[4]	1562	1883
	P		0.15
	SEM		92
	CV (%)	9.6	7.7
C	Control	1708	2102
	Diurnal Cooling	1371	2148
	Nocturnal Cooling	1534	2122
	Commercial[5]	277	1525
	P		0.36
	SEM		322
	CV (%)	52.8	15.2

[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Thermal-conditioning treatment: control treatment except that temp. in d5 was increased to 40 °C.
[5]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).
SEM - Standard error of the mean
Significant different at $P<0.05$

In Model C, it is remarkable to see the difference between the ambient and the bottle HSI during the commercial treatment. In Table 3.7, the ambient HSI during the

commercial treatment shows the lowest value of 277 °C*h among all the ambient HSI treatments (and is therefore different). However, the value difference between the commercial bottle HSI (1525 °C*h) and the other bottle HSI treatments values were more similar. This again suggests that the birds respond in a similar way (i.e. no differences in BW, FCR, feed consumption, water intake and mortality) under the different temperature treatments. An equation that can relate the time constant and the Heat Stress Index in order to improve barn temperature controls should be further investigated.

4. Summary

The focus of this project was to investigate the effect of environmental temperature fluctuations on poultry production traits (weight gain, feed intake, and feed conversion ratio) as well as bird mortality. The project also focused on water consumption, and the water-feed ratio of a commercial broiler strain.

Hypotheses 1 and 2 were both proven to be true. Diurnal fluctuating temperatures did help the birds to acclimatize to high temperatures thus maintaining a satisfactory bird live weight performance. The lowered nocturnal temperatures (to 15 °C) did maintain a satisfactory bird live weight performance and helped the birds cope with high mid-day temperature at the end of the rearing cycle. Although mortality showed no real difference among the treatments, it is important to note that none of the treatments increased mortality.

All the temperature treatments during the 42 days of rearing for each trial had no effect on the bird's final feed consumption. The similar values between treatment results can be related with the similarity between the daily average target temperature values. However, differences ($P<0.05$) between treatments were found during the four periods of

six hours (Figure 3.1 and Appendix B). These differences between periods suggest that the birds' adjust their feed and water intake patterns to the temperature fluctuations per period. Yet interestingly, all birds ended with a similar overall consumption.

This research found that hypothesis three was not true. The thermal conditioning at the age of 5d did not increase bird live-weight performance. Furthermore, there was no concrete evidence to show that it helped the birds cope with the high midday temperature peaks during the last two weeks of rearing thus reducing the mortality rate.

During the thermal-conditioning treatment the feed and water consumption showed a similar pattern to the control treatment because the same temperatures were applied to both during trial 1 except for day 5 when the thermal conditioning temperatures were applied. Final body weights did not show differences, suggesting that the birds did not respond to the different mean daily temperature on the two cooling strategies.

Water consumption showed more variation without being different during the experiments due to a mechanism to hydrate the body and dissipate heat as a response of temperature changes. The lack of difference in body weight performance among treatments including the commercial temperature treatment indicates that broilers can acclimatize to fluctuating warm temperatures. These results suggest that, if warm temperatures are imposed on the birds on a routine basis, the birds will acclimatize and little loss in body weight occurs. These data suggest that "smart" controllers need to be developed to impose high regular cyclic temperatures on the birds during the summer months. In this way, sudden hot temperature events during the last week of growth will not lead to mortality.

The resulting values for final BW and mortality in the thermal-conditioning treatment are not in concordance with Arjona *et al.* (1988), Yahav and Hurwitz (1996), and De Basilio *et al.* (2001) that affirm reduction in mortality. However, the temperature

fluctuations and the type of feed as well as the feeding restriction programs were not the same between projects making it difficult to affirm if the thermal conditioning did, in reality, help the birds adjust their metabolism for temperature peaks at the end of the rearing.

The influence of cyclic temperature treatments over final body weights did not show differences between and among trials suggesting that the birds appeared to have acclimatized to the warm cyclic temperatures. In addition, the closeness (similitude) of the mean daily temperature treatments, shown in Figure 3.6, can be the reason of the lack of differences in feed consumption, water consumption, feed conversion and final body weights.

In terms of hypothesis four, the conclusion reached was that air temperature at the bird level as measured by a thermistor located inside of a black bottle full of water does describe the bird's perception of thermal comfort to a degree. Indeed, further researched needs to occur in this area. The temperatures recorded by the black water bottles provided a possible answer as to how birds could perceive the heat stress around them. With the black bottle at the birds' level showing a time constant of 2.1 h, it is possible to appreciate that the birds themselves could also lag in the response to the ambient temperature. In fact, the black bottle was only filled to 1 kg, half the weight of the birds. Therefore, it could be concluded that the birds may have in fact experienced a 4.2-hour lag. These results are critical in understanding how the birds acclimatize to high temperatures. Without the shock of the sudden high increase or decrease in temperatures that would have likely led to high mortality, the birds acclimated to consistent hot weather temperature fluctuations.

5. Conclusions

The following conclusions were drawn from this study:

1. Fluctuating temperatures help birds to acclimatize to high temperatures thus maintaining a satisfactory bird live weight performance.
2. All the temperature treatments during the 42 days of rearing for each trial had no effect on the bird's final feed consumption.
3. The thermal conditioning at the age of 5d did not increase bird live-weight performance.
4. If average daily temperatures are kept under 28 °C and above 20°C no effect on bird performance will occur.
5. The black bottle at the birds' level showed a time constant of 2.1 h demonstrating that the birds' response also is dampened by fluctuating ambient temperatures.

6. Limitations and Recommendations

For futures projects related with heat stress it is recommended that relative humidity be constantly monitored to have a better description of the chamber environment. This will also enable easier result comparisons with other similar projects.

The major limitation of this project was the inability to relate the lack of differences in body weight and general physiological measurements such as bird's fat content, muscle development, changes in heart and blood characteristics among treatments. It is suggested that in the next project, these parameters be taken into consideration and measured.

Although the capabilities of the AEPEC chambers were improved after this project, individual chambers calibrations need to be done. From this calibration, the following information needs to be produced: calibration curves for fans flow rates (with and without

light traps), temperature sensors (thermistors) and an estimation of the air speed per chamber (recirculation system).

For this project, water and feed consumption were not measured from day 1 due to technical limitations; however, for future projects this will be possible because the feeder and water system demonstrated to be reliable. It will be possible to electronically measure water consumption after water troughs are removed from the chamber at day 4 when the chicks should be used to the nipple drinking system. It will be possible to measure feed consumption after the pan feeders are totally suspended from the beam above the floor. If the bottom part of the feeder makes contact with the floor (litter), the feed consumption readings will not be accurate.

A more reliable water bottle or similar device has to be created in order to simulate body shape and size of the birds (Chick-robot). The size of the device has to progressively change with the bird growth rate. The time constant parameter has to be associated with the growth rate so a better ambient temperature curve can be found. In order to obtain an even more accurate reading of the temperature perceived by the bird, the device should have a insulation or something similar that will represent the birds' feathers and tissues.

Further research is required to assess the differences in fat deposition, protein deposition, muscles (breast) weight , etc with the temperature fluctuations to know more precisely what type of temperature variation produce better quality of birds .

It is also recommended that instead of using 4 periods of 6 hours, future research should use 12 periods of 2 hours to better understand bird feed and water consumption as a response to heat stress.

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Appendix A.

Illustrations of Temperature Treatments Outputs

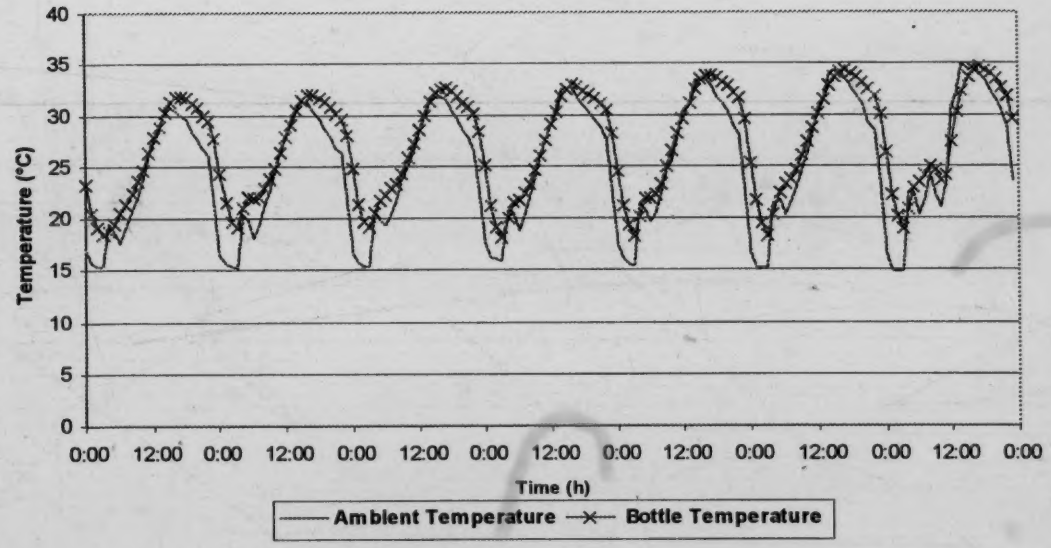

Figure A.1 Hourly temperatures readings from chamber 7 applying nocturnal cooling treatment from d36 to d42 during trial 2

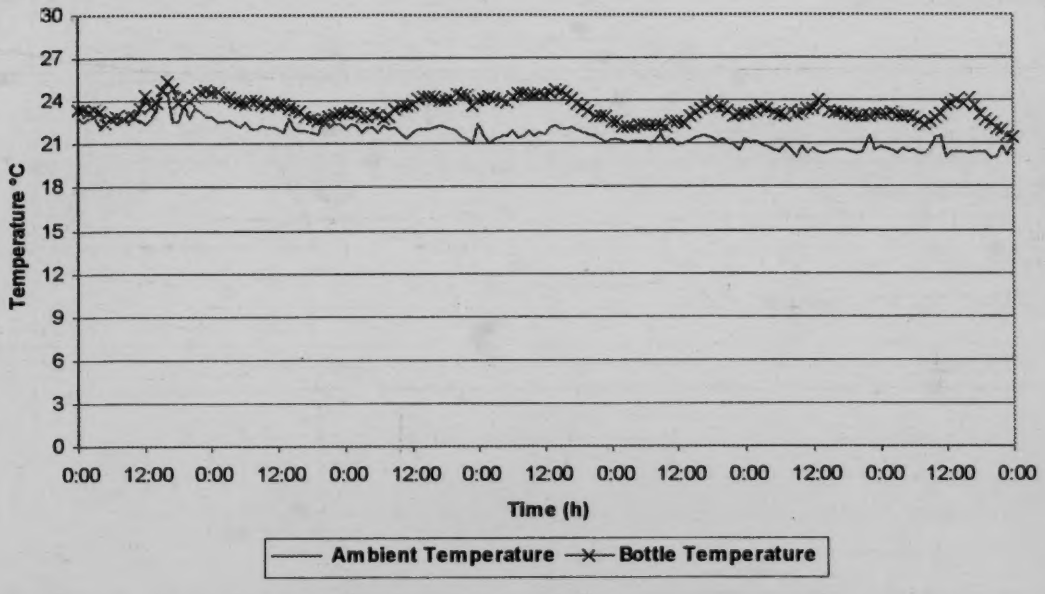

Figure A.2 Hourly temperatures readings from chamber 8 applying the commercial treatment from d36 to d42 during trial 2

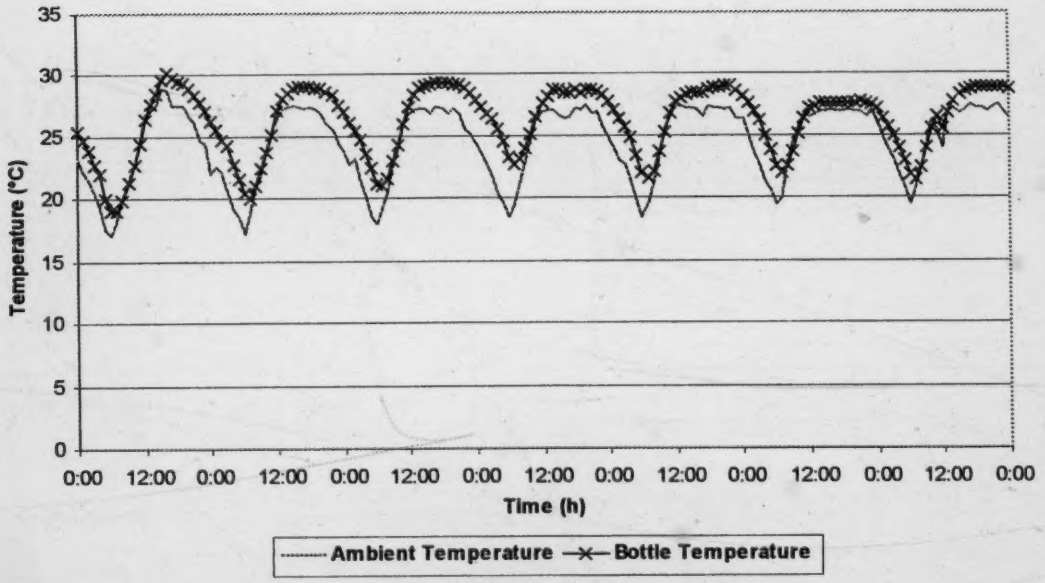

Figure A.3 Hourly temperatures readings from chamber 5 applying diurnal cooling treatment from day 36 to day 42 during trial 2.

Appendix B

Birds' Performance

Table B.1. Summary of weekly birds' feed consumption values (collected manually), birds' body weights, birds weight gain, feed conversion, and feed consumed by mortality during trial 1.

Age (wks)	Treatment	No.of Birds	Body Weight (g/bird)	Mortality (g)	Weight Gain (g/bird)	Feed consumption		Feed Conversion	
						Weekly (g/bird)	Cumulative (g/bird)	Weekly	Cumulative
1	Control	606	103.7	159.5	64.3	93.9	93.9	1.47	0.91
	Diurnal Cooling	611	109.4	14	69.9	95.9	95.9	1.37	0.88
	Nocturnal Cooling	608	110.9	75.9	70.1	96.9	96.9	1.39	0.87
	Thermal Conditioning	609	103.4	56.8	62.9	97.2	97.2	1.55	0.94
2	Control	605	260.5	73.5	156.7	233.1	327.0	1.49	1.26
	Diurnal Cooling	609	280.3	159.5	170.8	236	331.9	1.39	1.18
	Nocturnal Cooling	605	281.4	99.9	170.5	240.3	337.2	1.41	1.20
	Thermal Conditioning	607	259.8	167.3	156.5	234.1	331.3	1.50	1.28
3	Control	597	575.6	1607.3	315.2	491.3	818.2	1.58	1.42
	Diurnal Cooling	605	602.3	798.5	322.1	483.9	815.8	1.51	1.35
	Nocturnal Cooling	600	601.4	1173.6	320	486.9	824.1	1.53	1.37
	Thermal Conditioning	593	573.3	2585.6	313.5	496.2	827.5	1.62	1.44
4	Control	587	1029.4	4087.4	453.8	740.3	1558.5	1.67	1.51
	Diurnal Cooling	602	1093.8	1070	491.4	769.7	1585.5	1.58	1.45
	Nocturnal Cooling	594	1081.4	1872.2	480	763.5	1587.6	1.61	1.47
	Thermal Conditioning	588	1021.2	1436	447.9	770.2	1597.7	1.74	1.56
5	Control	580	1485.6	3715.8	456.3	987.5	2546.0	2.25	1.71
	Diurnal Cooling	599	1548.8	2160	455	1018	2603.5	2.27	1.68
	Nocturnal Cooling	587	1520.3	4155.7	438.9	1023.5	2611.1	2.42	1.72
	Thermal Conditioning	582	1422.7	2139.6	401.5	1010.3	2608.0	2.60	1.83
6	Control	577	2002.4	1948.3	516.8	1142.5	3688.5	2.23	1.84
	Diurnal Cooling	592	2039.4	5958	490.7	1142.4	3746.0	2.42	1.84
	Nocturnal Cooling	582	2039.2	4235	518.9	1139.8	3750.8	2.12	1.84
	Thermal Conditioning	579	2006.6	3693.4	583.9	1192.8	3800.8	2.12	1.89
	SEM				22.5			0.12	
	P				0.83			0.40	

[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Thermal-conditioning treatment: control treatment except that temp. in d5 was increased to 40 °C.
[5] Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).

Table B.2. Summary of weekly birds' feed consumption values (collected manually), birds' body weights, birds weight gain, feed conversion, and feed consumed by mortality during trial 2

Age (wks)	Treatment	No.of Birds	Body Weight (g/bird)	Mortality (g)	Weight Gain (g/bird)	Feed Consumption		Feed Conversion	
						Weekly (g/bird)	Cumulative (g/bird)	Weekly	Cumulative
1	Control	606	120.9	174.3	79.0	106.7	106.7	1.36	0.88
	Diurnal Cooling	605	120.8	34.6	78.7	102.9	102.9	1.32	0.85
	Nocturnal Cooling	609	126.8	50.1	84.3	105.9	105.9	1.27	0.83
	Commercial	610	129.0	42.1	87.0	108.5	108.5	1.25	0.84
2	Control	606	288.2	0.0	167.3	272.3	378.9	1.63	1.31
	Diurnal Cooling	602	294.6	12.0	173.8	285.5	388.5	1.65	1.32
	Nocturnal Cooling	606	306.2	225.5	179.4	286.3	392.2	1.60	1.28
	Commercial	608	308.3	277.0	179.3	295.2	403.7	1.65	1.31
3	Control	601	606.1	382.9	317.9	539.3	918.3	1.71	1.52
	Diurnal Cooling	597	648.1	339.1	353.5	560.4	948.9	1.60	1.46
	Nocturnal Cooling	600	651.5	406.2	345.3	551.2	943.3	1.61	1.45
	Commercial	605	658.2	9.0	349.9	567.4	971.2	1.63	1.48
4	Control	590	1042.2	13.0	436.1	784.7	1703.0	1.85	1.63
	Diurnal Cooling	595	1075.9	816.0	427.9	790.4	1739.3	1.86	1.62
	Nocturnal Cooling	596	1094.2	1866.7	442.7	807.7	1751.1	1.85	1.60
	Commercial	601	1045.3	3.5	387.1	785.7	1756.8	2.06	1.68
5	Control	588	1603.3	1176.4	561.2	1009.8	2712.8	1.81	1.69
	Diurnal Cooling	589	1632.7	1301.0	556.8	1031.9	2771.2	1.89	1.70
	Nocturnal Cooling	589	1624.2	10.5	530.0	1055.9	2807.0	2.04	1.73
	Commercial	593	1614.6	4707.0	569.3	1031.5	2788.3	1.86	1.73
6	Control	580	2053.0	5122.1	449.7	1010.7	3723.4	2.37	1.81
	Diurnal Cooling	583	2097.3	3923.5	464.6	1027.7	3798.9	2.30	1.81
	Nocturnal Cooling	579	2078.1	3667.5	453.9	1039.0	3846.0	2.47	1.85
	Commercial	587	2064.3	3323.0	449.7	1078.1	3866.4	2.50	1.87
	SEM				15.5			0.06	
	P				0.92			0.70	

[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Thermal-conditioning treatment: control treatment except that temp. in d5 was increased to 40 °C.
[5] Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).

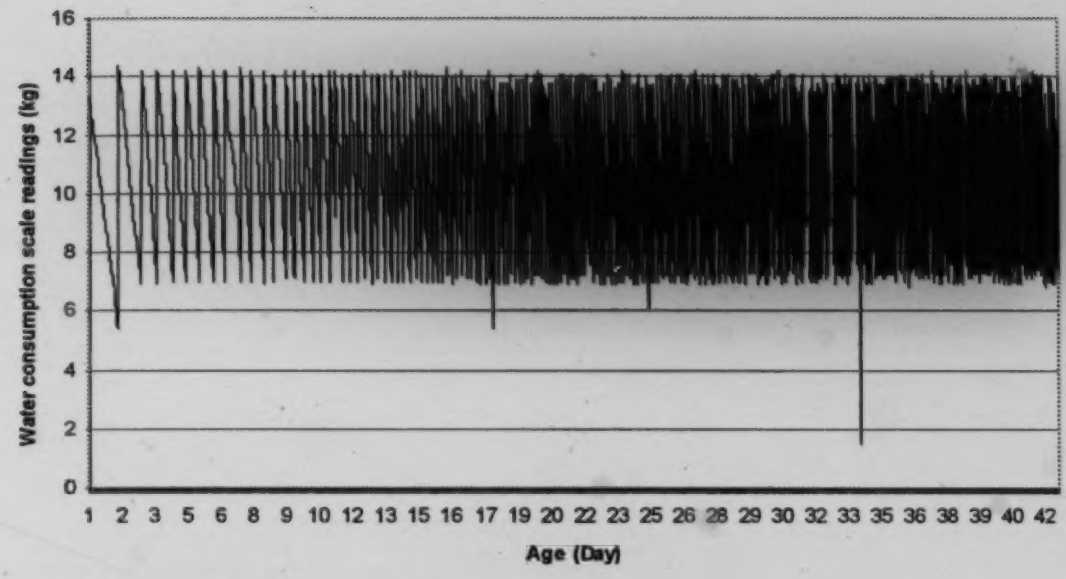

Figure B.1. Example of water consumption readings (every 10 minutes) from a nocturnal treatment chamber. Notice the increase in water consumption as evidenced by the closeness of each interval during the last 20d.

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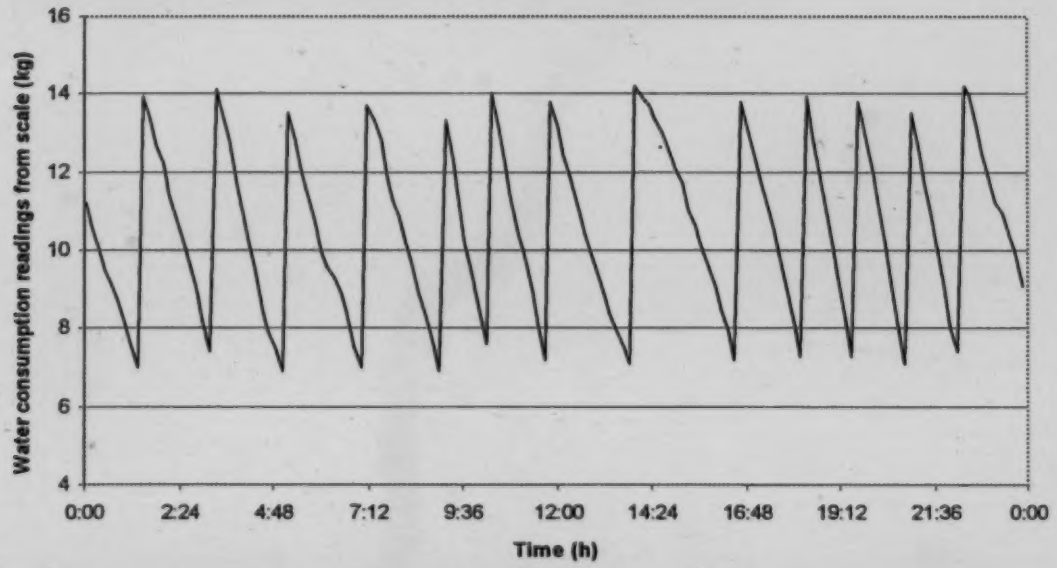

Figure B.2. Example of water consumption readings for day 41 collected every ten minutes during nocturnal cooling in one of the chambers. Notice the differences in time between water container fill intervals.

Table B.3. Summary for feed consumption (g/bird per h) in Trial 2 (Model C) from d29 to d42.

Bird Age in days	Treatments			
	Control[1] (g/bird/h)	Diurnal Cooling[2] (g/bird/h)	Nocturnal Cooling[3] (g/bird/h)	Commercial[4] (g/bird/h)
29	5.3	5.6	5.2	5.3
30	5.7	6.1	6.1	6.2
31	5.8	6.0	6.2	6.3
32	6.2	6.4	6.5	6.4
33	6.3	6.4	6.8	6.6
34	6.0	5.9	7.3	5.6
35	7.0	7.0	7.1	7.0
36	6.5	6.7	6.5	7.0
37	6.8	6.8	6.9	7.3
38	7.0	7.0	7.0	7.3
39	7.2	6.9	7.1	7.2
40	7.1	7.4	7.2	7.8
41	7.3	7.4	7.3	7.7
42	6.5	7.0	6.0	6.1
SEM	0.25	0.25	0.25	0.25
P	0.119	0.119	0.119	0.119

SEM - Standard error of the mean
Significance level stated at $P < 0.05$
[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).

Table B.4. Summary for water consumption (ml/bird per h) in Trial 2 (Model C) from d29 to d42d.

Bird Age in days	Treatments			
	Control[1] (ml/bird/h)	Diurnal Cooling[2] (ml/bird/h)	Nocturnal Cooling[3] (ml/bird/h)	Commercial[4] (ml/bird/h)
29	9.1	10.6	9.5	10.5
30	8.8	9.7	10.3	10.4
31	9.3	10.1	10.0	10.5
32	11.0	10.5	10.8	10.7
33	10.6	11.2	11.2	11.7
34	10.4	11.3	11.8	11.8
35	11.1	12.4	11.8	12.1
36	11.7	12.3	11.2	12.4
37	10.9	11.6	11.1	13.1
38	11.8	12.8	11.2	11.2
39	12.5	13.0	11.8	12.7
40	13.0	13.6	12.6	13.5
41	13.5	14.6	13.2	12.7
42	14.4	14.2	12.5	13.9
SEM	0.46	0.46	0.46	0.46
P	0.097	0.097	0.097	0.097

SEM - Standard error of the mean
Significance level stated at $P < 0.05$
[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).

Table B.5. Trial 1 and trial 2 combined feed and water intake per each treatment by periods from 29 to 42 d of age.

	Period	Treatment				
		Control[1]	Diurnal Cooling[2]	Nocturnal Cooling[3]	Thermal-Conditioning[4]	Commercial[5]
Feed Intake	1	6.0	6.0	6.0	5.9	6.4
	2	7.4	7.5	7.8	7.3	6.7
	3	6.3	6.8	6.3	6.2	6.9
	4	6.1	5.8	6.3	6.1	6.7
	SEM	0.13	0.13	0.13	0.18	0.18
Water Intake	1	9.5	9.8	9.2	9.4	11.8
	2	12.5	13.4	12.4	12.7	11.2
	3	11.9	12.3	11.9	12.7	12.8
	4	10.9	10.4	11.7	11.3	12.0
	SEM	0.23	0.23	0.23	0.57	0.32

[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Thermal-conditioning treatment: control treatment except that temp. in d5 was increased to 40 °C.
[5]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).
SEM - Standard error of the mean
Significance level stated at $P < 0.05$

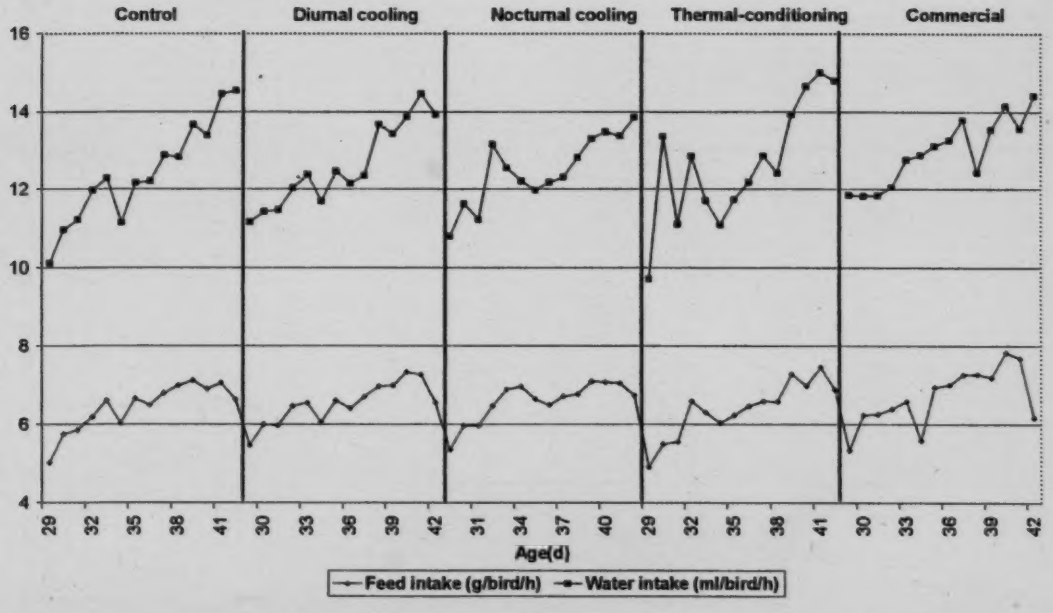

Figure B.3. Daily Feed and water consumption values for all treatments in g/bird per h and mL/bird per h (29 to 42 d).

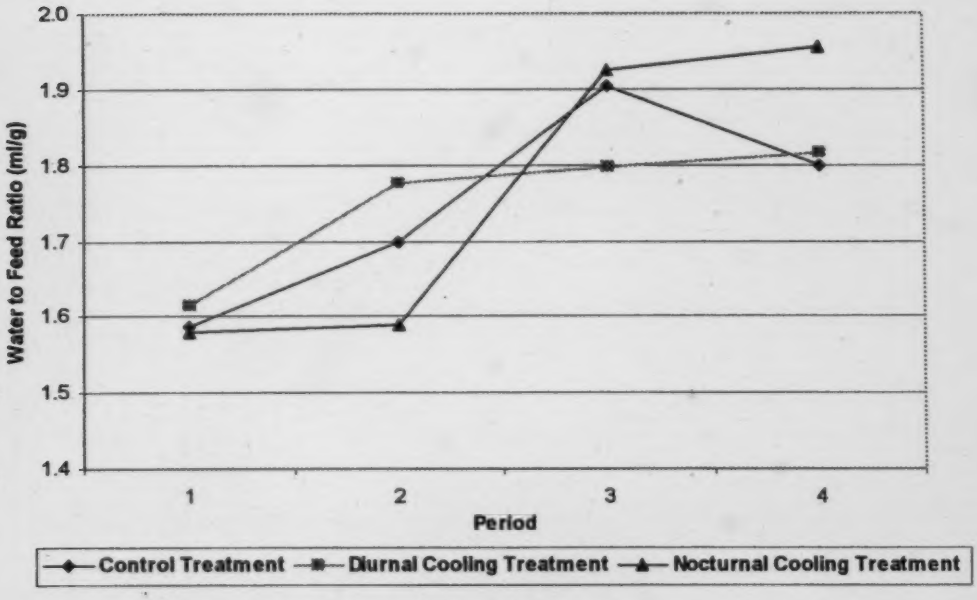

Figure B.4. Water to feed ratio for model A (29 to 42d).

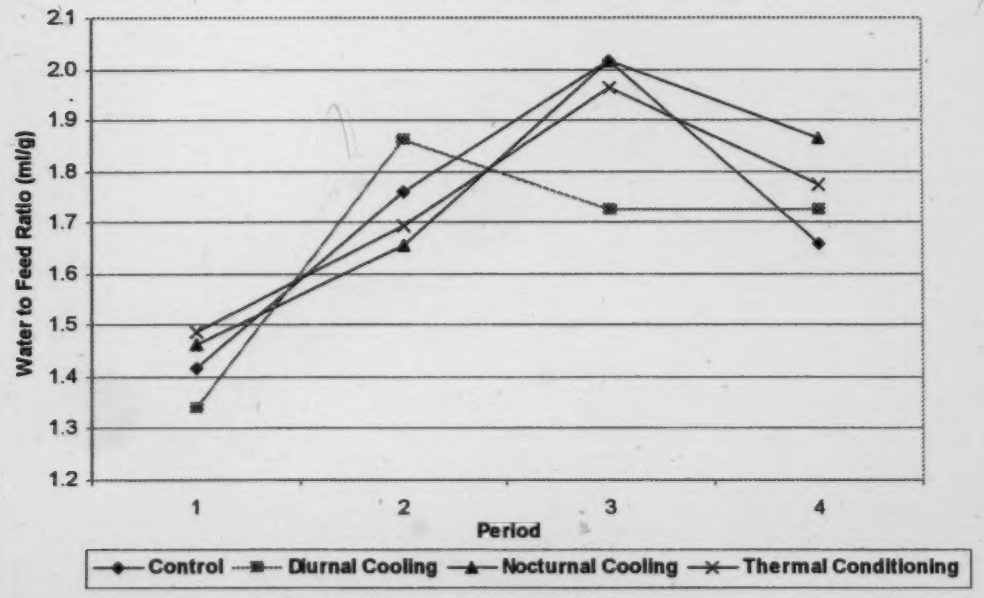

Figure B.5. Water to feed ratio for model B (29 to 42d)

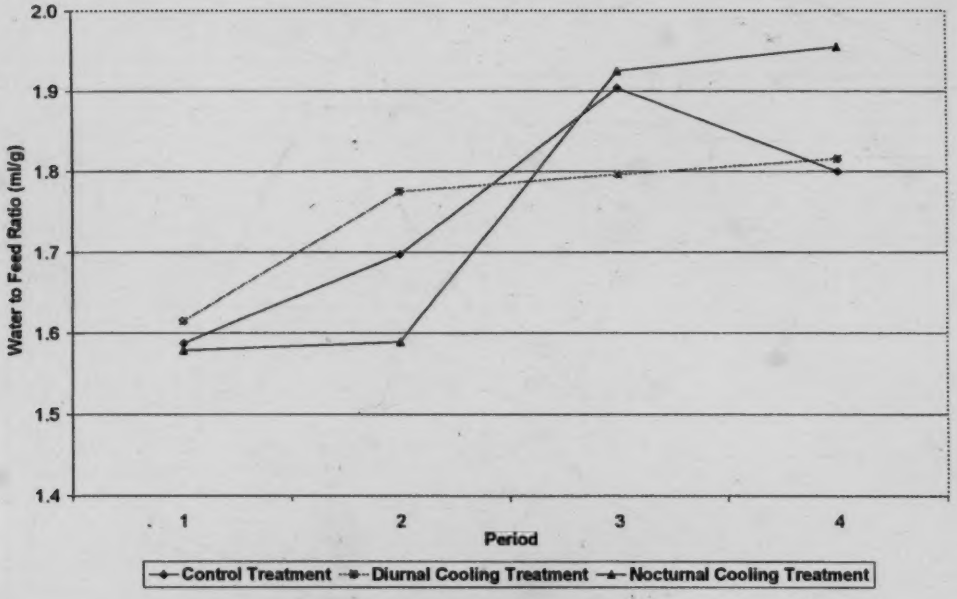

Figure B.6. Water to feed ratio for model C (29 to 42d)

Appendix C.

AEPEC chamber air flow calibration values

Table C.1. Moving average final temperatures for all treatments in trial 2. Mean absolute temperatures differences for 1, 5, 10, 15, 20 and 24 h from moving average temperatures

Time Moving Average hours	Control[1]	Diurnal Cooling[2]	Nocturnal Cooling[3]	Commercial[4]
1	2.5	2.2	3.5	0.4
5	2.3	2.0	3.1	0.3
10	1.8	1.6	2.4	0.3
15	1.2	1.0	1.6	0.2
20	0.5	0.5	0.7	0.1
24	0.1	0.1	0.1	0.0

[1]Control treatment: cyclic temp d29 (15 to 25 °C until d42 (20 to 35°C).
[2]Diurnal cooling treatment: control treatment except that the highest temperature allowed was 28 °C.
[3]Nocturnal cooling treatment: control treatment except 15 °C from 11p.m. to 3 a.m.
[4]Commercial treatment: Initial temp. 35 °C (d1) and decreased until d42 (20 °C).

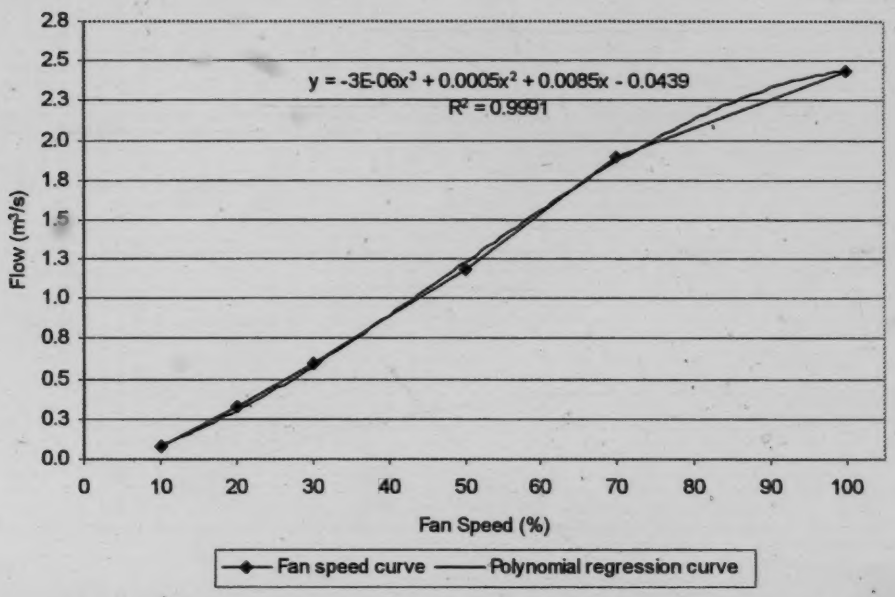

Figure C.1. AEPEC's chambers calibration curves of one exhaust ventilation fan with its polynomial regression.

Table C.2. Calibration values of one exhaust ventilation fan for the AEPEC chambers

Fan speed (%)	Level	Depth (cm)	Port A	B	C	D	E	F	Mean (m/s)	Flow (m^3/s)
10	1	1.4	0.11	0.14	0.36	0.24	0.12	0.05	0.17	
	2	4.6	0.11	0.15	0.47	0.3	0.08	0.09	0.20	
	3	8.1	0.22	0.12	0.54	0.25	0.28	0.15	0.26	
	4	12.7	0.41	0.14	0.58	0.44	0.45	0.37	0.40	
	5	19	0.44	0.35	0.58	0.41	0.57	0.53	0.48	
							Total mean		0.30	0.07
20	1	1.4	0.5	0.45	0.49	1.55	1.07	0.35	0.74	
	2	4.6	1	0.57	0.55	1.31	1.02	0.43	0.81	
	3	8.1	1.3	1.65	0.78	1.94	1.42	0.6	1.28	
	4	12.7	2	1.71	1.45	1.85	1.87	1.83	1.79	
	5	19	1.97	1.88	2.12	1.87	1.94	2	1.96	
							Total mean		1.32	0.32
30	1	1.4	0.81	1.33	0.62	0.79	0.86	0.9	0.89	
	2	4.6	0.81	0.81	1.88	1.96	2.23	0.71	1.40	
	3	8.1	1.84	1.58	2.9	3.34	3.22	2.09	2.50	
	4	12.7	3.77	3.74	3.68	3.44	3.72	3.71	3.68	
	5	19	3.93	3.81	3.72	3.38	3.84	3.76	3.74	
							Total mean		2.44	0.60
50	1	1.4	1.75	2.03	1.78	1.39	2.57	1.53	1.84	
	2	4.6	1.86	1.75	2.45	3.88	3.96	1.77	2.61	
	3	8.1	5.83	3.59	5.49	6.09	7.14	4.98	5.52	
	4	12.7	7.18	7.03	6.75	7.61	6.89	7.52	7.16	
	5	19	7.34	7.14	7.12	6.02	7.14	7.05	6.97	
							Total mean		4.82	1.18
70	1	1.4	2.78	3.31	2.99	3.65	2.9	2.36	3.00	
	2	4.6	2.96	2.75	3.36	6.53	6.75	2.89	4.21	
	3	8.1	8.02	6.86	7.66	10.7	11.2	9.44	8.98	
	4	12.7	11	11.3	10.55	11.7	11.5	11.5	11.26	
	5	19	10.8	11.35	10.8	12.05	11.1	10.9	11.17	
							Total mean		7.72	1.89
100	1	1.4	3.37	5.11	4.86	5.34	3.99	3.33	4.33	
	2	4.6	3.53	3.73	4.5	8.05	7.69	5.03	5.42	
	3	8.1	11.8	10.35	9.37	13.25	14.2	12.85	11.97	
	4	12.7	13.6	14.25	13.65	14.35	14.65	13.95	14.08	
	5	19	13.3	13.95	13.25	15	14.4	13.3	13.87	
							Total mean		9.93	2.44